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DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
Panama City, Florida 32407

NAVY EXPERIMENTAL DIVING UNIT
Report No. 9-80
UNMANNED EVALUATION OF U.S. NAVY EX-16 UBA
PRE-PRODUCTION MODEL

JAMES R. MIDDLETON

MAY 1980

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Submitted:	Reviewed:	Approved:
J. R. Middleton	J T Harrison	R A Bornholdt
J. R. MIDDLETON Test Engineer	J. T. HARRISON LCDR, USN T & E Department Head	R. A. BORNHOLDT CDR, USN Commanding Officer
	W. H. Spaur	
	W. H. SPAUR CAPT, USN/MC Senior Medical Officer	
	M J Harwood	
	M. J. HARWOOD LCDR, Royal Navy EX-16 Project Officer	

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oxygen partial pressure

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ABSTRACT

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Table of Contents

GLOSSARY

ADM	advanced development model
ATA	atmospheres absolute
BPM	breaths per minute
Canister Breakthrough	point at which CO_2 concentration in the inhaled gas reached 0.5 percent surface equivalent
^oC	temperature in degrees Centigrade
cmH_2O	centimeters of water pressure (differential)
CO_2	carbon dioxide gas
EDF	Experimental Diving Facility
^oF	temperature in degrees Fahrenheit
FSW	feet of seawater
H.P. Sodasorb	high-performance sodasorb
kg-m/l	breathing work in kilogram meters per liter ventilation
ltv	The tidal volume of air breathed in and out of the lungs during normal respiration
lpm	liters per minute (flow rate)
NEDU	Navy Experimental Diving Unit
O_2	Oxygen
OSF	Ocean Simulation Facility
ΔP	pressure differential (cmH_2O)
PPM	Pre-Production Model
Po_2	Oxygen partial pressure
psig	pounds per square inch gauge
RMV	respiratory minute volume in liters per minute

GLOSSARY (CONTINUED)

SEV	surface equivalent value
Temp	temperature
T_{exp}	Exhaled gas temperature
T_{in}	Inspired gas temperature
UBA	underwater breathing apparatus

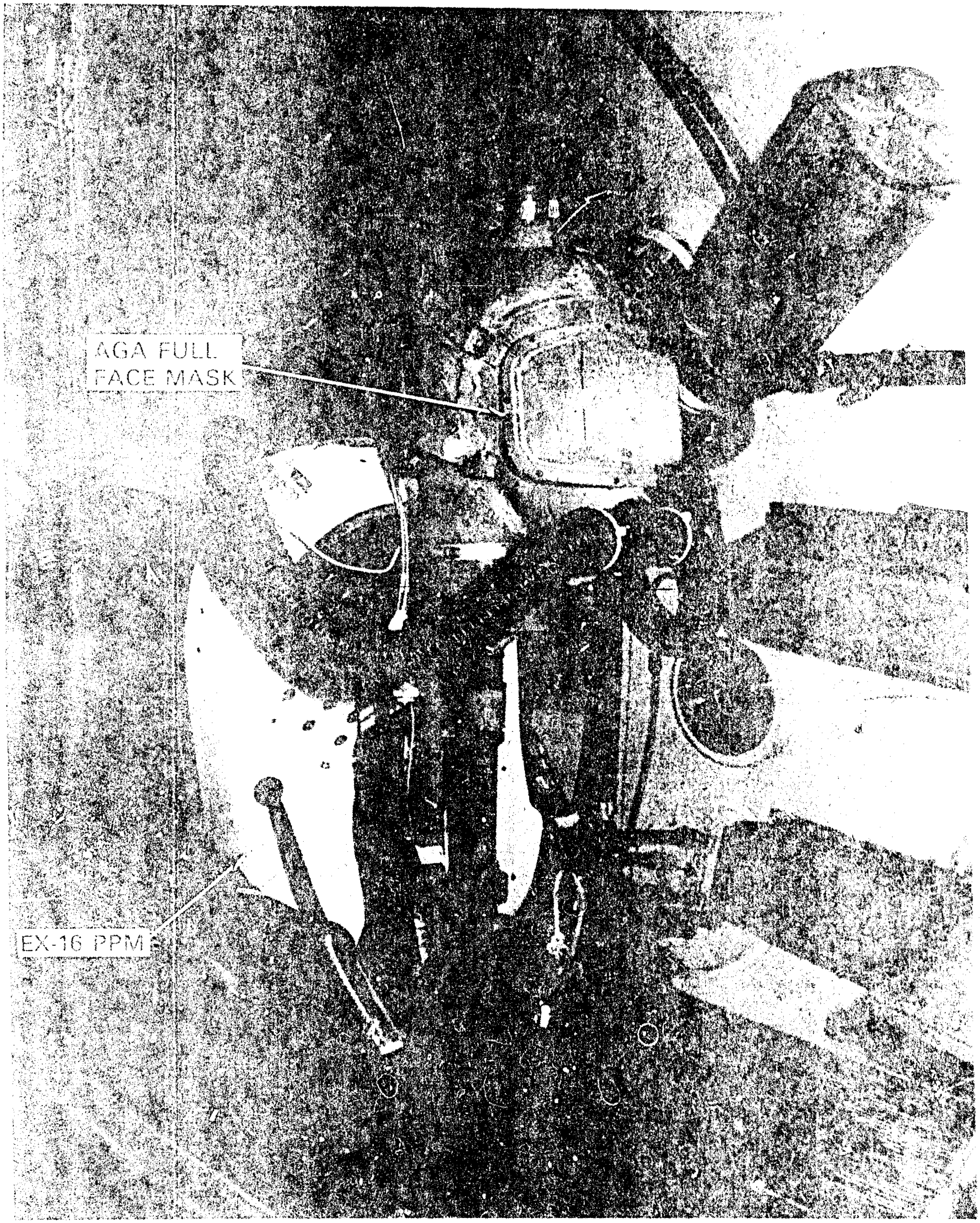

FIGURE 1 - UBA EX-16 PPM

INTRODUCTION

Unmanned testing by NEDU evaluated the U.S. Navy UBA EX-16 closed circuit rebreather considering three separate parameters:

(1) Breathing resistance to a depth of 300 feet using helium-oxygen diluent and to 150 feet using air diluent.

(2) Maximum canister duration in water temperatures ranging from 29°F to 90°F.

(3) Maintainability of required Po_2 set point.

The EX-16 (Figures 1 and 2) was tested in conjunction with a non-magnetic Full Face Mask and AGA hoses (Figure 3). Two types of non-return valves were evaluated for use in the mask:

(a) the standard silicon mushroom valves supplied with the AGA Mask

(b) Koegel valves

Breathing resistance tests were performed on both configurations to determine which style valve required the least amount of respiratory work by the diver. In addition, breathing resistance tests were performed on the EX-16 in conjunction with an AGA two hose mouthpiece. This mouthpiece utilized the same silicon mushroom valves found in the AGA Full Face Mask. The purpose of these tests was to establish performance capabilities of the EX-16 at depth and at varying temperatures.

Equipment Description

The Underwater Breathing Apparatus (UBA) EX-16 is a Low Influence Signature (LIS) closed circuit, mixed gas, constant partial pressure oxygen, underwater life support system developed to support the low magnetic and acoustic signature requirements of Explosive Ordnance Disposal (EOD). The breathing medium is kept at a predetermined partial pressure of oxygen (Po_2) set-point by use of oxygen sensors that monitor, evaluate, and control the level via a battery operated electronic module. The major individual components under development to support the Low Influence Signature (LIS) requirement consist of a Light Emitting Diode (LED) primary display mounted in the face mask; a plastic cased, rechargeable non-magnetic battery; a solid state, semi-conductor, expendable electronics package, an LIS oxygen control valve, and a Liquid Crystal Display (LCD) secondary display. In addition the CO_2 scrubber assembly of the EX-16 uses Lexan materials and is replenished through the top.

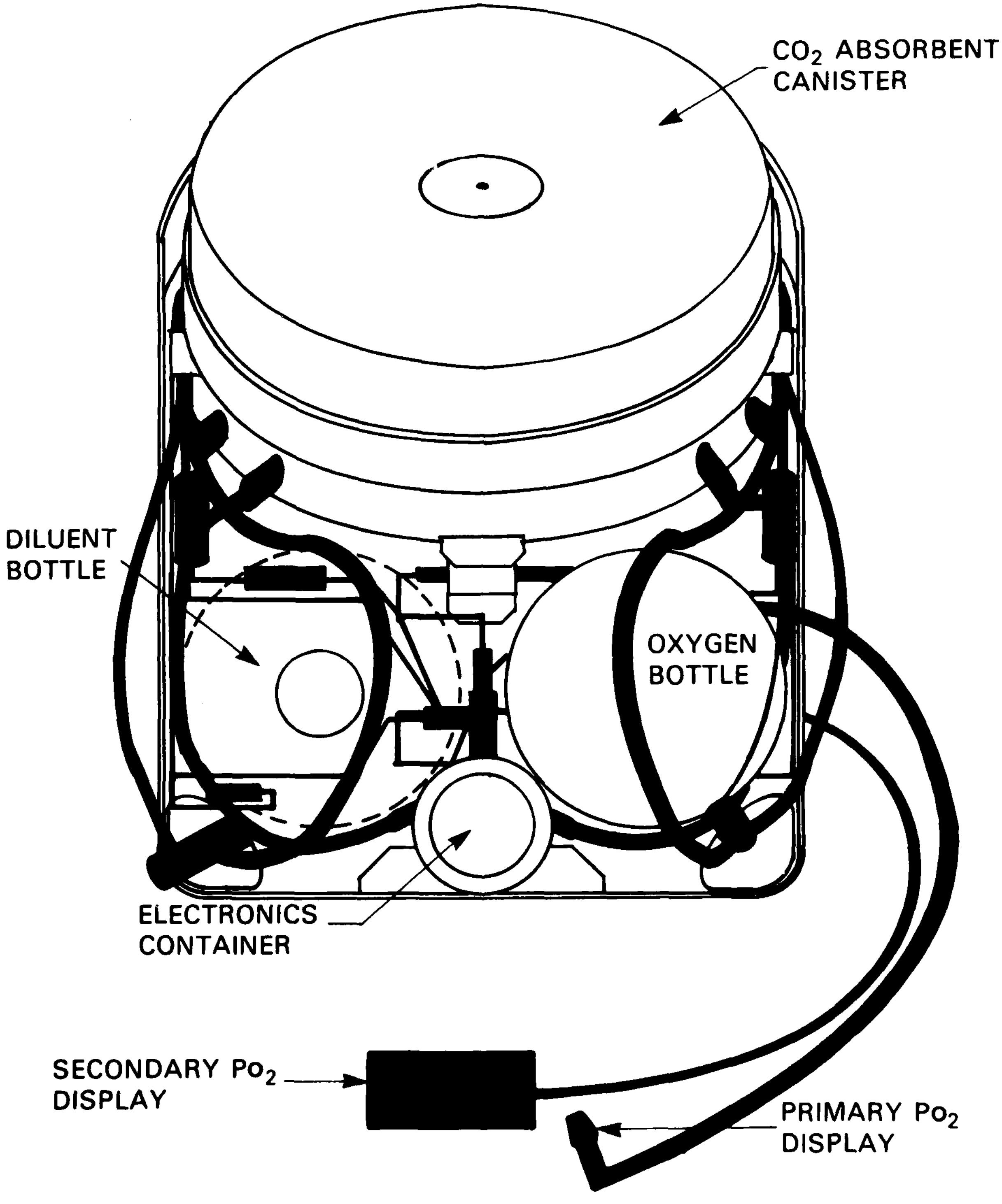

FIGURE 2 - UBA EX-16 SCHEMATIC
TOP VIEW - BREATHING GAS SUPPLY, ELECTRONICS PACKAGE
AND CO_2 ABSORBENT CANISTER

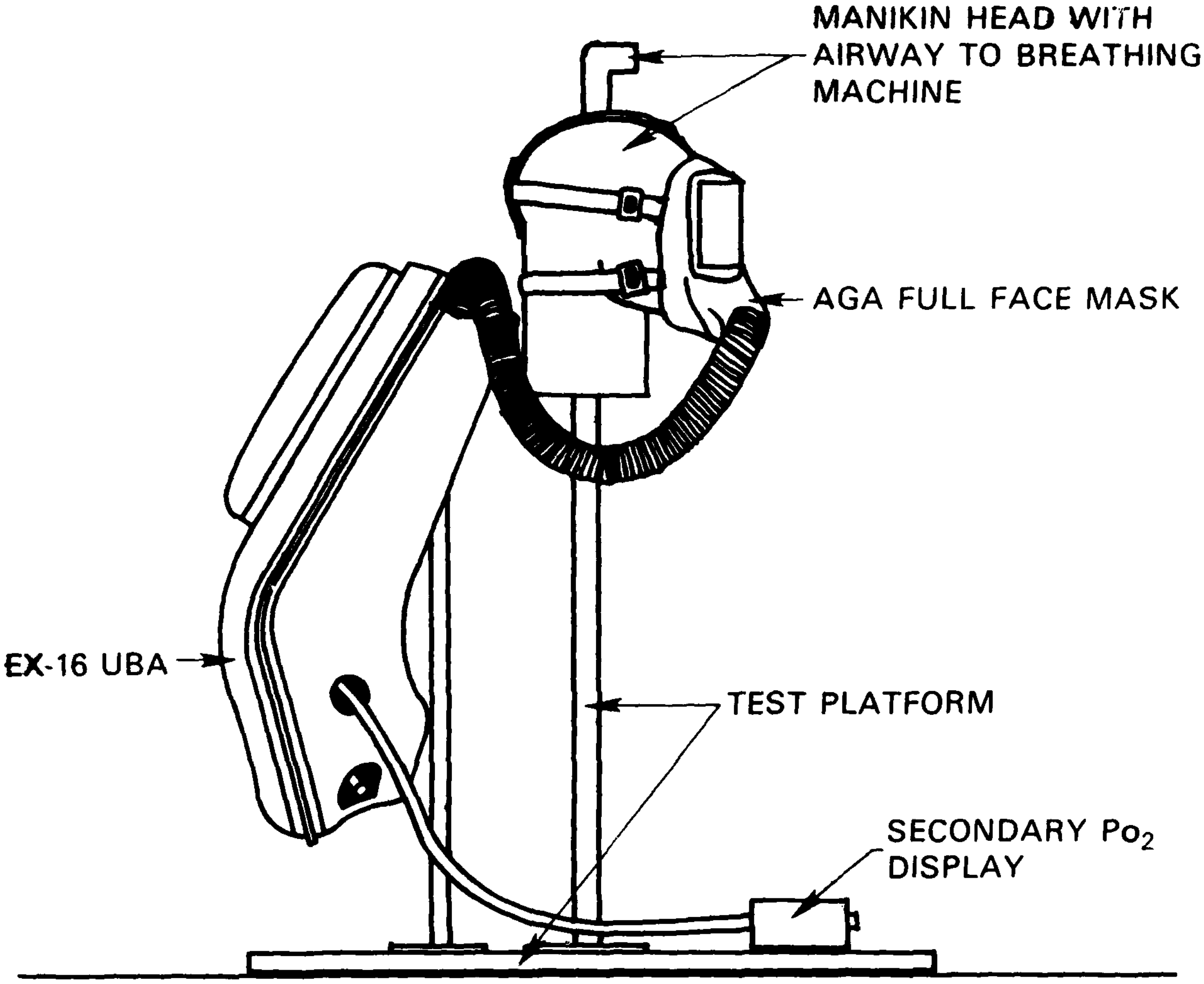

FIGURE 3 - UBA EX-16 IN UNMANNED TEST MODE

Functional Description

The EX-16 is a closed circuit rebreather which recirculates the diver's respired gases. The system is capable of providing approximately 595 liters (21 cu. ft.) of oxygen (O_2).

Most components are fabricated of fiberglass, polycarbonate, nylon, brass, neoprene, or some other non-magnetic material. By necessity, certain components such as the oxygen and diluent bottles (high pressure components) are fabricated of materials such as Inconel 718 which could have a magnetic signature imparted to them. The components and materials used in the MK-16 have been specially selected and assembled such that while operating the complete assembly will not exhibit a magnetic signature greater than five gamma (γ) at a distance of 0.1 meter (4.5 in.).

During normal operation, the diver inhales a mixture of O_2 and diluent gas which is contained in the breathing loop. The diver's exhaled gas is recirculated back to the scrubber housing where it is filtered through the scrubber where carbon dioxide (CO_2) is removed. As the partial pressure of O_2 (Po_2) in the breathing loop drops, O_2 sensors housed in the center section signal the electronics assembly which activates the O_2 control valve, emitting additional O_2 to the breathing loop.

As the diver descends, the EX-16 adds diluent to maintain the pressure of the diver's breathing loop gas supply equal to ambient pressure. Diluent gas is added to the breathing loop in response to actuation of the diluent addition valve by the motion of the molded neoprene diaphragm as a result of the reduced volume in the breathing loop.

While the diver is working at his assigned depth, his Po_2 is monitored by the three O_2 sensors. When the diver's Po_2 goes below a predetermined setpoint, the sensors send a signal to the O_2 addition valve, via the electronics assembly, which opens to allow additional O_2 into the breathing loop. Oxygen addition continues until the Po_2 in the breathing loop is brought back to the predetermined setpoint. A second signal is then sent by the electronics assembly causing the O_2 addition valve to close.

The primary display indicates relative oxygen concentration and qualitative electronics status. The primary display is mounted on the right side of the diver's mask and indicates the Po_2 in the breathing loop by means of two (red and green) Light Emitting Diodes (LEDs). Functional indications are: Normal O_2 (steady green), High O_2 (blinking green). Low O_2 (blinking red), and transition from one state to another, low battery voltage and/or failure of logic components (blinking red and green). In the event of a dead battery or blown fuse, the display is blanked.

The diver is also equipped with a secondary display which directly monitors the O_2 sensors and the secondary battery level. The secondary display consists of a single Liquid Crystal Display (LCD) which is powered independently. The manual by-pass valves permit the diver to control the addition of diluent or O_2 to the breathing loop should the automatic system fail.

TEST PROCEDURE

Test Plan

The complete test plan is provided in Appendix A. All applicable NEDU specifications for unmanned testing were followed. Test equipment is listed in Appendix B and illustrated in Figure 4. A breathing machine simulated inhalation and exhalation at varied depths, water temperature and diver work rates.

Controlled Parameters

Breathing Resistance Tests

Breathing resistance controlled parameters:

1. EX-16 Diluent: Air and HeO_2 (84/16)

2. Breathing rate/tidal volume/RMV/Simulated Diver Work Rate

a.	15 BPM	1.5 Liters	22.5 RMV	Light
b.	20 BPM	2.0 Liters	40.0 RMV	Moderate
c.	25 BPM	2.5 Liters	62.5 RMV	Moderately Heavy
d.	30 BPM	2.5 Liters	75.0 RMV	Heavy
e.	30 BPM	3.0 Liters	90.0 RMV	Extreme

3. Exhalation/inhalation time ratio: 1.00/1.00

4. Breathing waveform: Sinusoid

5. Incremental descent stops:

   a. Air - 0 to 150 FSW in increments of 33 FSW
   b. HeO_2 - 0 to 300 FSW in increments of 33 FSW

6. Diluent Supply Pressure: 1000 psig

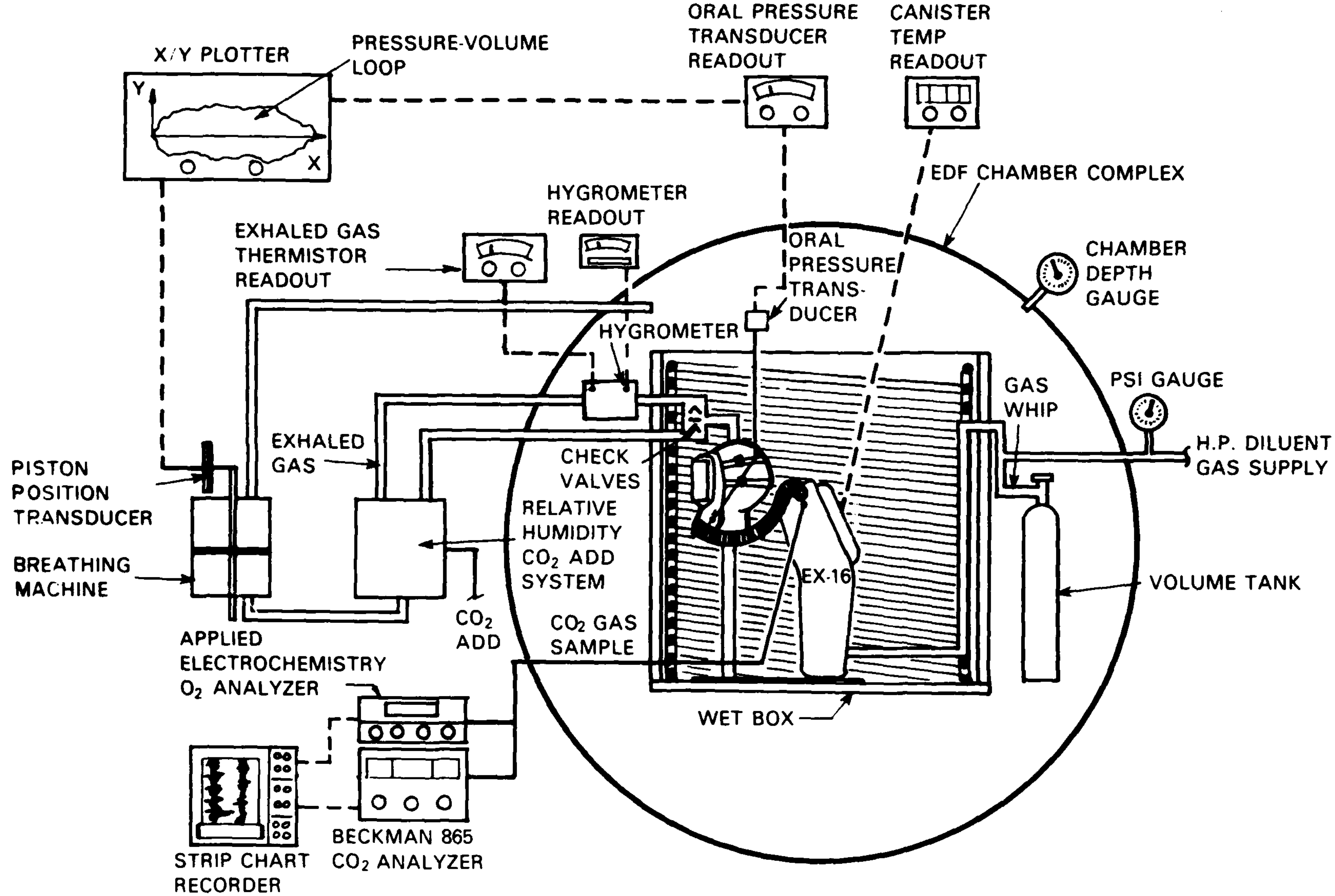

FIGURE 4 - TEST SETUP

Canister Duration Tests

Canister duration controlled parameters:

1. EX-16 Diluent: Air and HeO_2 (84/16)

2. CO_2 breakthrough tests were conducted using H.P. sodasorb at work temperatures of 90, 70, 60, 50, 40, and 29°F.

3. CO_2 add rate during simulated rest/work

   a. 0.9 lpm at 23.0 RMV (2.0 ltv x 11.5 BPM) for 4 minutes (rest)
   b. 2.0 lpm at 50.0 RMV (2.0 ltv x 25.0 BPM) for 6 minutes (work)

   NOTE: The CO_2 add rate is cycled between 0.9 and 2.0 lpm at 4 and 6 minute intervals, respectively, for the duration of the canister tests to simulate a man at rest and work on a bicycle ergometer.

4. Relative humidity of exhaled gas: 90 (±2) percent

5. Exhaled gas temperature followed a formula of expired gas temperature equals 24 + .32 times inspired gas temperature (T_{exp} = 24 + .32 T in °C).

   NOTE: T_{in} is assumed to be 10°C above ambient water temperature.

Water Temperature (°F)					
29	40	50	60	70	90
80	83.5	86.7	90	93	98.6
Exhaled Gas Temperature (°F)					

6. Depths for canister duration tests

   a. Air - 30, 50, 100, 150 FSW
   b. HeO_2 - 30, 100, 200, 300 FSW

7. Diluent Supply Pressure: 1000 psig

Oxygen Consumption Tests

1. O_2 consumption rates:

   a. 0.9 lpm at 23.0 RMV (simulated rest cycle)
   b. 2.0 lpm at 50.0 RMV (simulated work cycle)

2. EX-16 Diluent: Air and HeO_2 (84/16)

3. Depths for oxygen consumption tests:

   a. Air - 0 to 150 FSW
   b. HeO_2 - 0 to 300 FSW

4. Diluent Supply Pressure: 1000 psig

Measured Parameters

Breathing Resistance Tests

Breathing resistance maximum ΔP (cm of H_2O) (i.e. total pressure excursion between exhalation and inhalation cycles)

Canister Duration Tests

1. CO_2 level out of scrubber, expressed as percentage of S.E.V.

2. Canister bed temperatures in $^{\circ}F$

Oxygen Consumption Tests

O_2 level in inhalation hose (% SEV)

Computed Parameters

Respiratory work (Kg-m/l) from ΔP vs volume plots obtained during breathing resistance tests.

Data Plotted

The following plots were developed from data received in the breathing resistance tests:

1. Breathing resistance maximum ΔP vs depth at each RMV tested

2. Respiratory work vs depth at each RMV tested

The following plots were developed from data received in the canister duration tests:

1. CO_2 (% of SEV) out of scrubber vs time

2. Canister bed temperature vs time

The Po_2 inhaled gas (SEV) vs time plot was developed from data received in the oxygen consumption tests.

RESULTS AND DISCUSSIONS

Breathing Resistance

The breathing resistance of the EX-16 was measured in three different configurations using both air and helium as the diluent. The three test configurations were as follows:

1) EX-16 UBA/AGA Full Face Mask with stock mushroom non-return valves and AGA hoses

2) EX-16 UBA/AGA Full Face Mask with Koegel non-return valves and AGA hoses

3) EX-16 UBA/AGA two hose mouthpiece with stock mushroom non-return valves and AGA hoses

A total of five RMVs were tested at all normal operating depths to simulate light through extreme diver work rates. Breathing resistance was measured using a pressure transducer located in the oral-nasal cavity of the mask and the oral cavity of the mouthpiece.

Figures 6 through 11 (Appendix C) show performance using the mushroom and Koegel non-return valves on air and HeO_2 in both full face mask and mouthpiece configurations.

In all tests the mushroom and Koegel valves give almost identical performance. There is also no discernable difference in performance between AGA Mouthpiece with the stock mushroom valve and the AGA Full Face Mask with those same non-return valves. Under all test conditions approximately 50 percent of the total breathing resistance was attributable to exhalation and 50 percent to inhalation.

All test modes showed breathing resistance to be less than 35 cmH_2O pressure at work rates up to 62.5 RMV when using air. Seventy-five (75) RMV produced pressure differentials beyond this point at 132 FSW and 90 RMV reached this point at 66 FSW.

When using HeO_2 as the diluent, breathing resistance was substantially less than values obtained using air. Pressure differentials did not exceed 30 cmH_2O at any depth up to 75 RMV and 90 RMV remained below 30 cmH_2O to a depth of 198 FSW.

Breathing Work

Breathing work is a measure of the respiratory energy expended by the diver to operate a UBA. When used in conjunction with the peak inhalation and exhalation breathing resistance data, it provides a useful tool in the evaluation of underwater breathing apparatus.

In all test modes on air (Appendix D - Figures 12 through 14) breathing work remained below 0.30 kg-m/l at depths above 99 FSW until 90 RMV was reached. This correlates well with breathing resistance measurements in showing the UBA capable of supporting heavy diver work rates. A Helium Oxygen mix significantly reduces required breathing work and at no time did the breathing work exceed 0.30 kg-m/l (Figures 15 through 17).

CO_2 Absorbent Canister Tests

A total of 65 canister duration studies were conducted as part of the EX-16 UBA evaluation. Canister endurance, depth, breathing mix, and water temperatures for the test series are summarized in Table 1. Data yielded very consistent results. Duration differences of more than two or three work/rest cycles were never obtained when comparing various test runs with identical conditions. As was shown in earlier tests (reference 1), the canister is quite sensitive to how the absorbent is packed. The optimum amount of absorbent that realized the best results was consistently eight pounds ($\pm$ four ounces). Consequently, great care was taken to assure uniformity of canister packing in order to achieve consistent results. All canister duration tests were performed using the AGA Full Face Mask with stock mushroom valves.

Canister Bed Temperature Results

Figures 18 through 33 (Appendix E) depict temperature at selected locations within the canister bed. These temperatures are plotted at 10 minute intervals as the % CO_2 (SEV) rises to 1.0.

Tests were carried to 1.0% CO_2 SEV to gain a complete picture of canister bed life. Figure 5 illustrates the position of the thermistors in the canister.

The canister bed temperature progression is not plotted for each EX-16 canister test conducted. However, a representative graph for cold and warm water at each depth tested is included. On runs where only cold water test data is plotted, the canister durations were long enough that warm water tests were not warranted. The pattern of temperature rise and fall at the different locations in the canister bed provides a useful means of determining which parts of the bed are most efficiently used (i.e., the higher the temperature, the more effective the bed use). While the thermistors nearest the inner and outer canister walls are generally the highest temperatures, the #2 thermistor located in the center of the bed is also consistently high, indicating that channeling is not a problem and the absorbent bed is uniformly used. The canister proved to be so consistent that at the end of each test the following was observed: The top 1 to 1-1/2 inches was unused with very little evidence of channeling. Below this unused layer the sodasorb showed uniform blue indicator coloration.

Canister Duration Results

Figures 34 through 60 (Appendix F) plot percent CO_2 SEV versus time. Due to the great number of tests conducted and the EX-16's consistent performance, only representative plots of each set of test conditions are shown. The average times of all tests are summarized in Table 1. The canister duration plots correspond to those for canister bed temperature vs. time respectively. Numerous tests were carried all the way to 2.0% CO_2 SEV. These tests indicate that the canister does not quickly reach 2.0% after passing the 1.0% CO_2 mark.

NOTE: Moisture content in the H.P. Sodasorb ranged from 13.5% to 15.0%.

Oxygen Consumption Test Results

A series of tests simulating oxygen consumption by the diver were conducted to determine whether or not the EX-16 could maintain Po_2 in the UBA at its required setpoint of 0.7 ATA absolute.

The tests were conducted at various depths on both air and HeO_2 mixes. Maximum normal ascent and descent rates were simulated before reaching test depths where standard rest/work cycles were begun.

The diver-inhaled gas was monitored using an instrument specifically designed to measure oxygen. This value was compared to the EX-16 secondary readout being displayed to the diver.

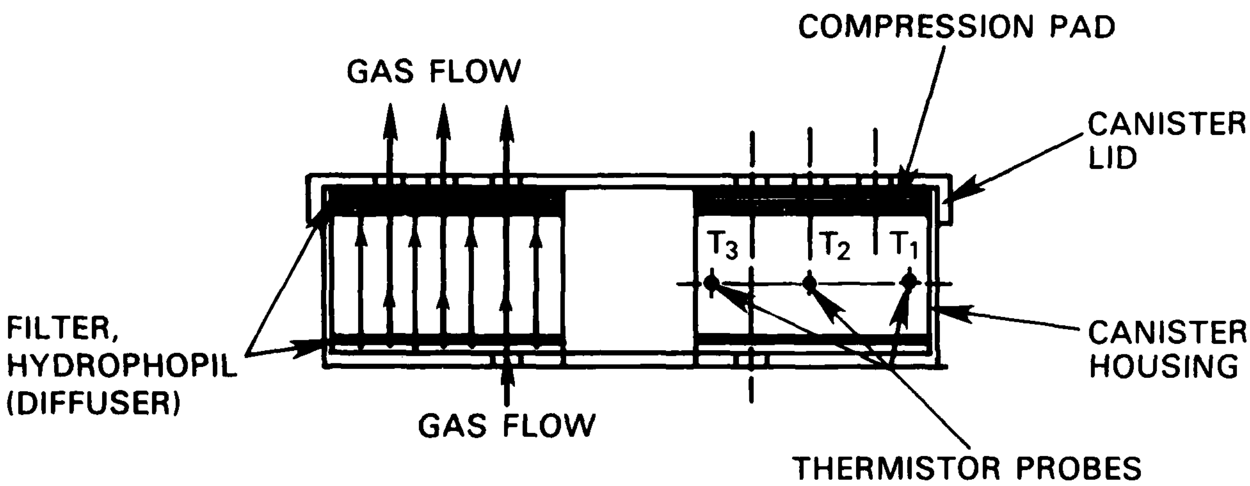

FIGURE 5 - THERMISTOR LOCATIONS IN EX-16 CANISTER

TABLE 1

EX-16 Unmanned Canister Duration Tests
Summary of Results

NOTE: A minimum of two tests were run at each set of test conditions.

I. Air Diluent Tests

Run Number	Depth (FSW)	Water Temp (°F)	Mean Time 0.5% SEV (Min)	Mean Time 1.0% SEV (Min)	Mean Time 2.0% SEV (Min)
1	30	29	280	335	
2	30	70	258	294	
3	50	29	270	332	
4	50	40	256	322	
5	50	90	259	300	
6	100	29	109	154	
7	100	40	233	302	
8	100	50	267	336	
9	100	70	262	333	
10	150	29	71	108	147
11	150	40	97	145	218
12	150	50	217	286	
13	150	60	266	319	
14	150	70	218	293	

II. HeO_2 Diluent Tests

Run Number	Depth (FSW)	Water Temp (°F)	Mean Time 0.5% SEV (Min)	Mean Time 1.0% SEV (Min)	Mean Time 2.0% SEV (Min)
15	30	40	279	328	
16	100	29	273	330	
17	100	70	293	344	
18	150	29	186	258	
19	150	40	276	333	
20	200	29	139	188	240
21	200	40	124	189	
22	200	50	210	290	369
23	200	60	299	367	
24	300	29	71	96	147
25	300	40	114	149	
26	300	50	120	190	288
27	300	70	242	310	

The Po_2 results show the EX-16 oxygen sensing and addition system under steady state conditions maintains 0.7 ATA setpoint Po_2 within 0.74 ATA on the high side and 0.60 ATA on the low side with the diver at work or rest regardless of depth or breathing mix. It was observed that during a 75 feet per minute compression on HeO_2 from the surface to 300 FSW, the max Po_2 level upon reaching the bottom was 1.8 ATA with the diver consuming 2.0 lpm O_2 all the way to the bottom. From this point it took 8.5 minutes for the working diver to return to the setpoint level of 0.7 ATA Po_2.

The same maximum descent rate conditions using air as a diluent and traveling from the surface to 150 FSW were tested. Results showed a maximum Po_2 upon reaching the bottom of 1.50 ATA. From this point it took 7.5 minutes for the working diver to return to the setpoint level of 0.7 ATA Po_2.

A maximum ascent rate of 120 feet per minute was tested to determine how low the Po_2 would go when coming immediately from 300 to 33 FSW. The rig was controlling adequately around 0.7 ATA Po_2 before leaving the bottom. At 33 FSW Po_2 had dropped to 0.20 ATA with the diver consuming 2.0 lpm of oxygen during ascent. However the rig recovered to 0.7 ATA within three minutes.

Figure 61 (Appendix G) shows how the O_2 add valve begins adding oxygen when the O_2 content level goes below 0.60 ATA and shuts off when the O_2 sensors receive a reading of 0.60 ATA or above.

CONCLUSIONS

Results of this test series generated the following conclusions:

1. Breathing resistance of the EX-16 UBA when used in conjunction with the AGA Full Face Mask or AGA Two Hose Mouthpiece is improved over the original Scott mouthpiece. No significant difference was observed between the performance of the AGA Mushroom or Koegel Valves.

2. Carbon dioxide absorbent canister durations are comparable to those seen in the prototype unit tested in reference (1). Canister durations under identical test conditions were quite consistent, varying only 10 to 20 minutes between tests. Tests which were carried to 2.0% CO_2 SEV did not indicate a tendency for the canister to break through quickly after reaching 1.0% CO_2 SEV. In general, durations show the canister to be operating near maximum efficiency for this design without external heating of the absorbent bed.

3. O_2 setpoint control is adequate and meets current performance requirements in the unmanned mode.

REFERENCES

1. NEDU Report No. 11-79, Evaluation of U.S. Navy UBA EX-16 Prototype Closed Circuit Rebreather, James R. Middleton, December 1979

APPENDIX A

Test Plan

APPENDIX A

A. Test plan for breathing resistance evaluation:

(1) (a) Ensure the EX-16 is set to specification and is working properly.

(b) Chamber on Surface.

(c) Calibrate transducer.

(d) Open makeup gas supply valve to test UBA.

(e) Adjust breathing machine to 1.5 liter tidal volume and 15 BPM and take readings.

(f) Adjust breathing machine to 2.0 liter tidal volume and 20 BPM and take readings.

(g) Adjust breathing machine to 2.5 liter tidal volume and 25 BPM and take readings.

(h) Adjust breathing machine to 2.5 liter tidal volume and 30 BPM and take readings.

(i) Adjust breathing machine to 3.0 liter tidal volume and 30 BPM and take readings.

(j) Stop breathing machine.

(2) (a) Pressurize chamber to 33 FSW.

(b) Repeat Steps (1) (e) - (j)

(3) (a) Pressurize chamber to 66-150 FSW in 33 FSW increments.

(b) Repeat Steps (1) (e) - (j).

(4) (a) Bring chamber to surface.

(b) Check calibration on transducers.

(5) Repeat steps 1 through 4 to depth of 300 FSW in 33 FSW increments using HeO_2 (84/16) as the diluent.

B. Test plan for CO_2 canister duration evaluation

(1) (a) Ensure that EX-16 is set to factory specifications and is working properly using H.P. Sodasorb.

(b) Chamber is on surface.

(c) Calibrate transducers and Beckman 865 analyzers.

(d) Open makeup gas supply valve to test UBA (Diluent: Air)

(e) Water temperature to be 90°F.

(f) Start humidity add system.

(g) Press chamber to 30 FSW.

(h) Start CO_2 add and maintain following procedure until 1.0% SEV CO_2 is reached:

4 minutes at 0.9 lpm CO_2 add 2.0 liter tidal volume and 11.5 BPM

6 minutes at 2.0 lpm CO_2 add/2.0 liter tidal volume and 25 BPM

(i) Take data every 10 minutes until breakthrough.

(2) Repeat steps (1) (a) - (i) at 70, 60, 50, 40, and 29°F.

(3) Repeat steps (1) and (2) at 50, 100 and 150 FSW.

(4) Repeat steps (1) and (2) using HeO_2 (84/16) at depths of 30, 100, 150, 200 and 300 FSW.

Note: A minimum of two tests are to be conducted at each set of test conditions.

C. Test plan for O_2 addition/control system evaluation:

(1) (a) Ensure that EX-16 is set to factory specifications and is working properly.

(b) Chamber on surface.

(c) Calbrate oral pressure tranducer and S-3A O_2 analyzer.

(d) Open makeup gas supply valve to test UBA (Diluent: Air).

(e) Water temperature to be 70°F.

(f) Press chamber to 30 FSW at 75 FPM.

(g) Start CO_2 add system with the normal rest/work cycles.

(h) Start O_2 consumption systems when chamber reaches the bottom in cycle with the CO_2 add system.

(i) Take data every minute for 15 minutes.

(2) Repeat steps (1) (a) - (i) at 60, 90, 120, and 150 FSW.

(3) Repeat steps (1) (a) - (i) except using HeO_2 (84/16) as a diluent and take data at 50, 100, 150, 200, and 300 FSW.

APPENDIX B

Test Equipment

APPENDIX B

Test Equipment Used

1) Breathing machine
2) Validyne pressure transducer Model DP-15 with 1.00 psid diaphragm (oral pressure)
3) Wet test box
4) The heating and cooling system from the EDF life support loop used to control water temperature during the canister duration tests
5) MFE Model 715M x-y Plotter
6) Validyne CD-23 transducer readout (1 each)
7) Applied Electrochemistry Model S-3A for analyzing O_2 in breathing loop
8) NEDU EDF Chamber Complex
9) External gas supply pressure gauge
10) Chamber depth gauge
11) Test UBA: UBA EX-16 (PPM-1)
12) Breathing machine piston position transducer/CO_2 add system/humidity add system
13) Relative humidity sensor
14) Strip chart recorder
15) O_2 consumption simulation system
16) YSI Model 731 Thermistors for monitoring canister bed temperature and water temperature (4 each)
17) Digitec HT-5820 Thermistor Readout (4 each)
18) Beckman 865 Infrared Analyzer for monitoring CO_2 out of the scrubber (1 each)

APPENDIX C

Breathing Resistance Data
Figures 6 through 11

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Stock Mushroom Non-Return Valves
DILUENT: Air
DILUENT SUPPLY PRESSURE: 1000 psi

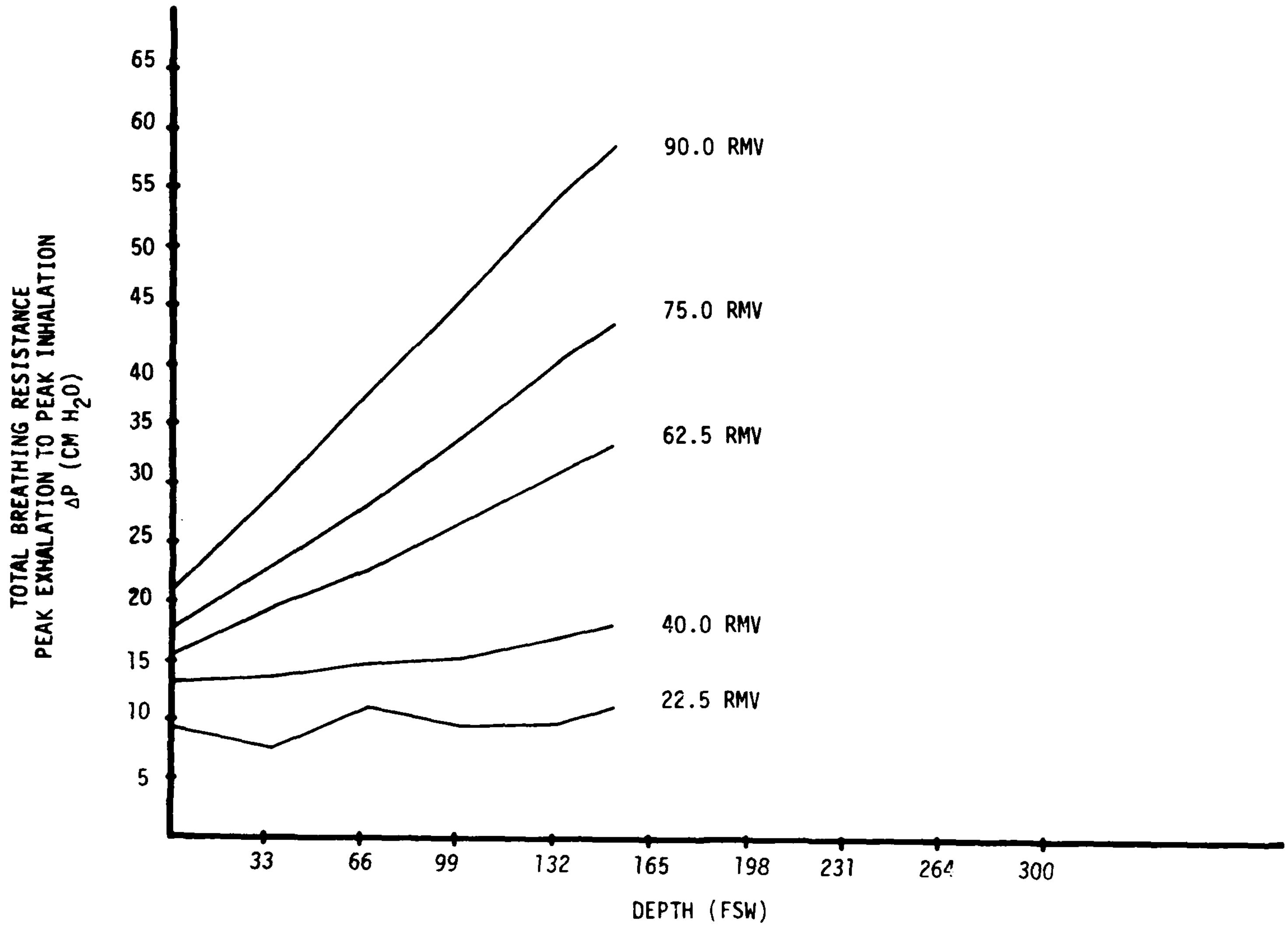

Figure 6 - BREATHING RESISTANCE MAXIMUM ΔP Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Koegel Non-Return Valves
DILUENT: Air
DILUENT SUPPLY PRESSURE: 1000 psi

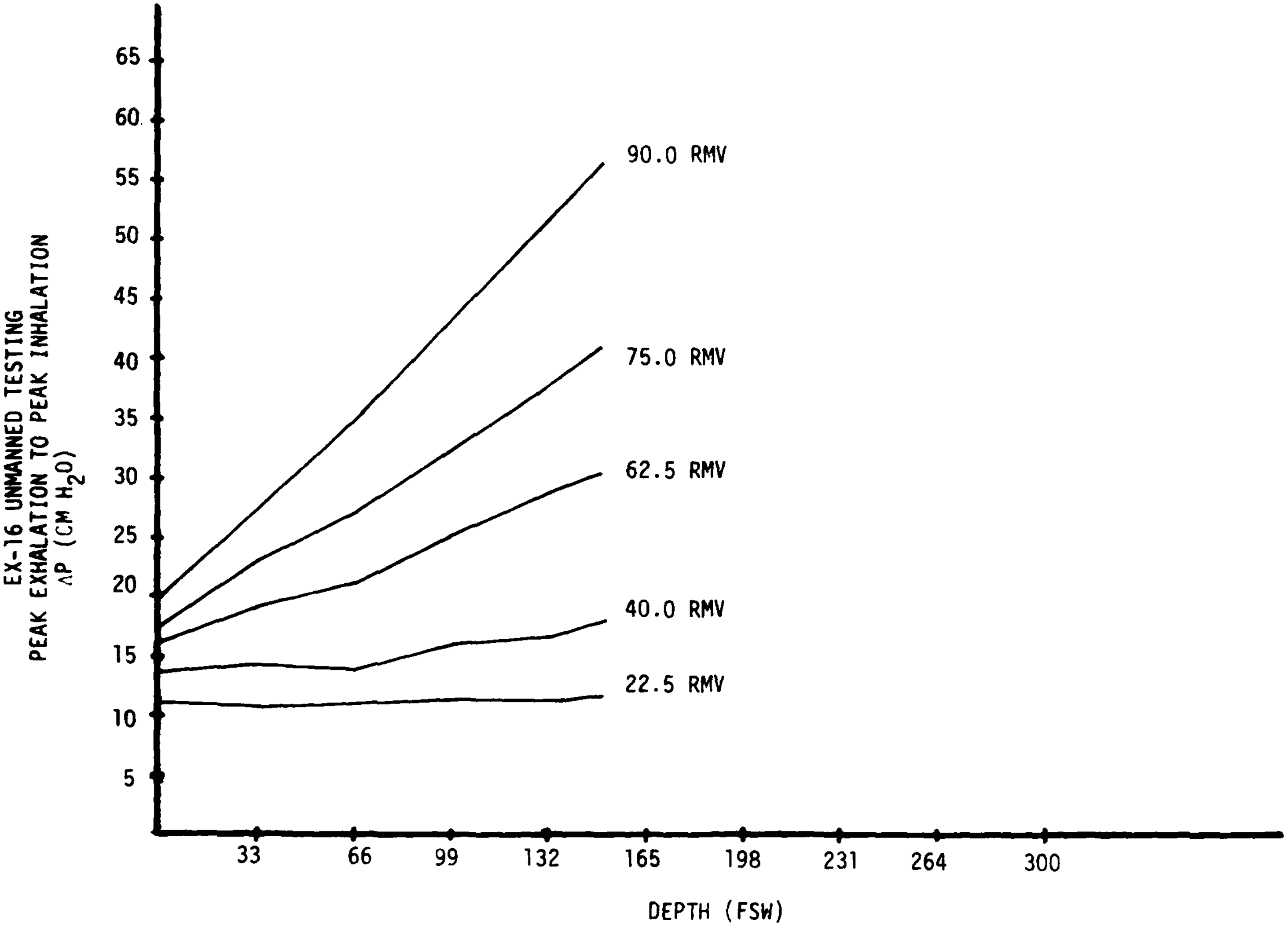

FIGURE 7 - BREATHING RESISTANCE MAXIMUM ΔP Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Mouthpiece with Stock Mushroom Non-Return Valves
DILUENT: Air
DILUENT SUPPLY PRESSURE: 1000 psi

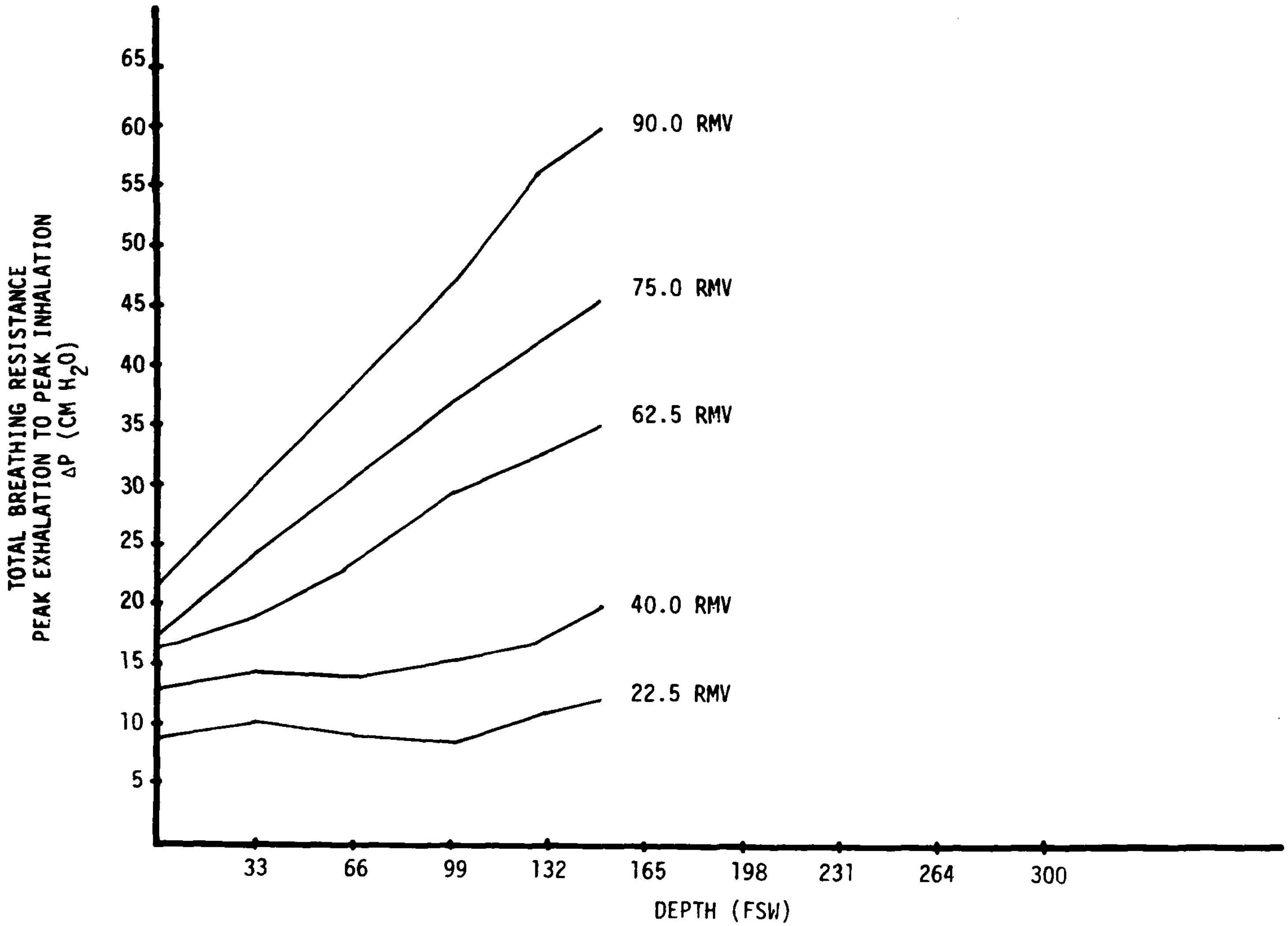

FIGURE 8- BREATHING RESISTANCE MAXIMUM Δ P Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Stock Mushroom Non-Return Valves
DILUENT: HeO_2
DILUENT SUPPLY PRESSURE: 1000 psi

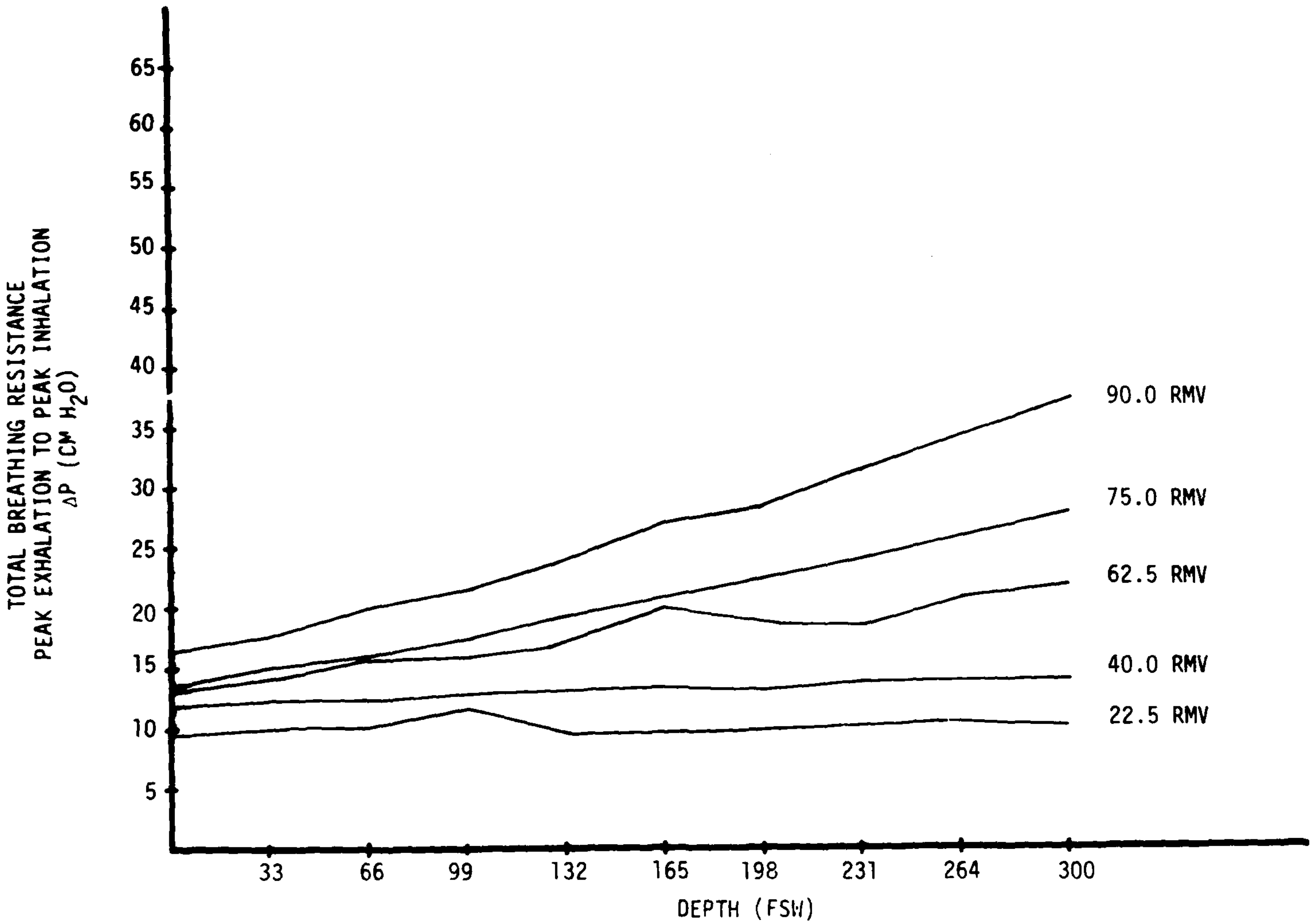

FIGURE 9 - BREATHING RESISTANCE MAXIMUM ΔP Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Koegel Non-Return Valves
DILUENT: HeO_2
DILUENT SUPPLY PRESSURE: 1000 psi

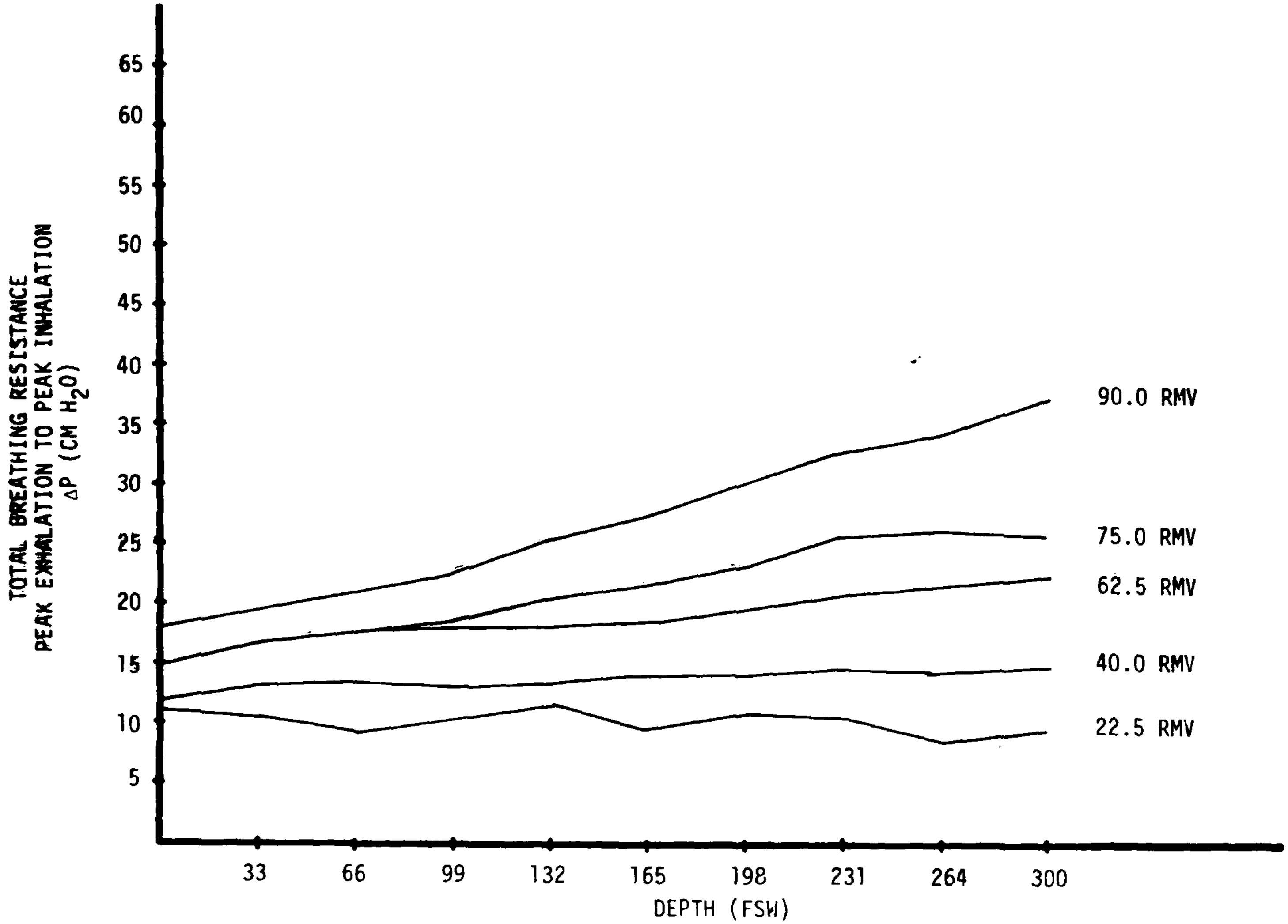

FIGURE 10 - BREATHING RESISTANCE MAXIMUM ΔP Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Mouthpiece with Stock Mushroom Non-Return Valves
DILUENT: HeO_2
DILUENT SUPPLY PRESSURE: 1000 psi

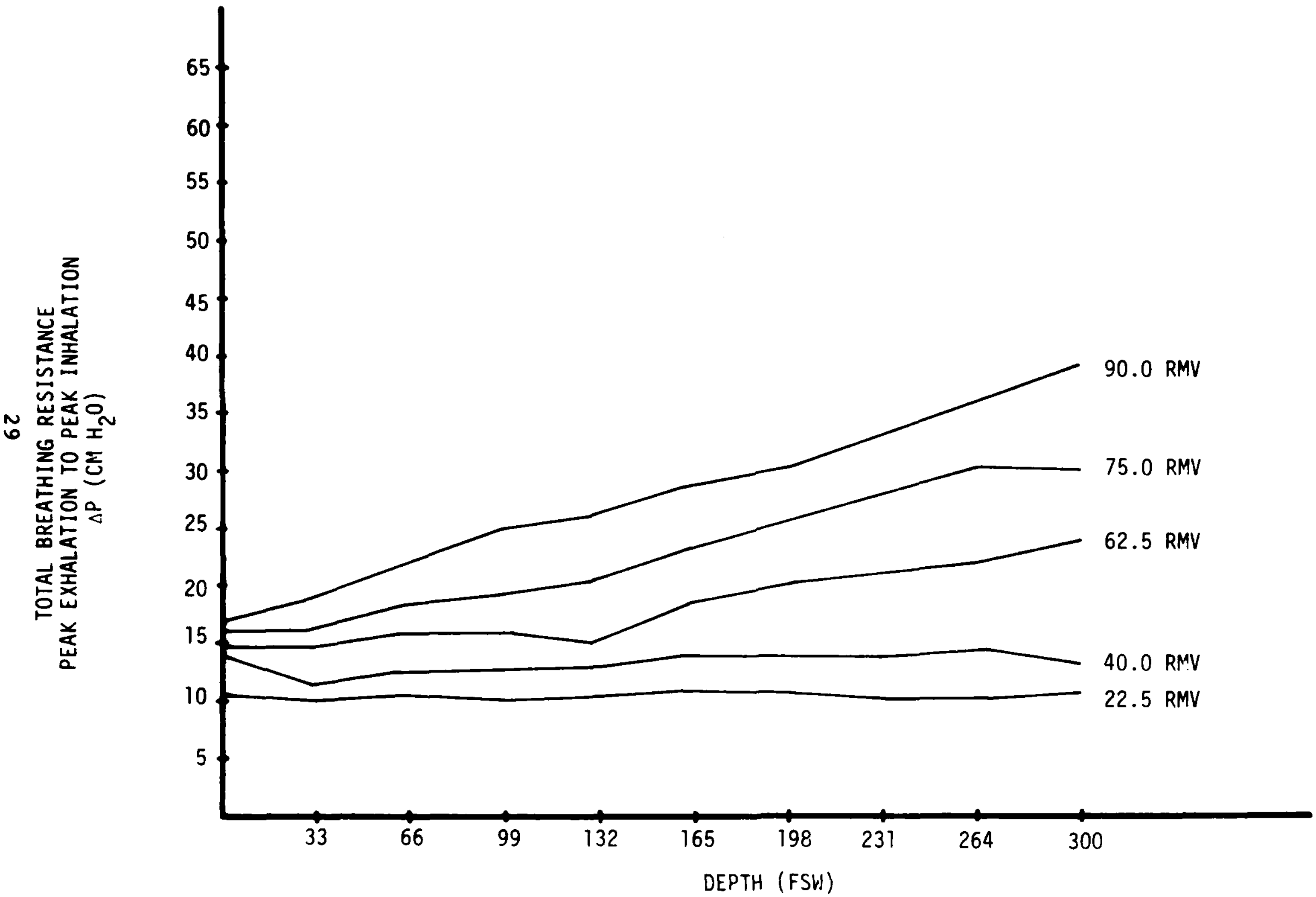

FIGURE 11- BREATHING RESISTANCE MAXIMUM Δ P Vs DEPTH

APPENDIX D

Breathing Work Data
Figures 12 through 17

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Stock Mushroom Non-Return Valves
DILUENT: AIR
DILUENT SUPPLY PRESSURE: 1000 psi

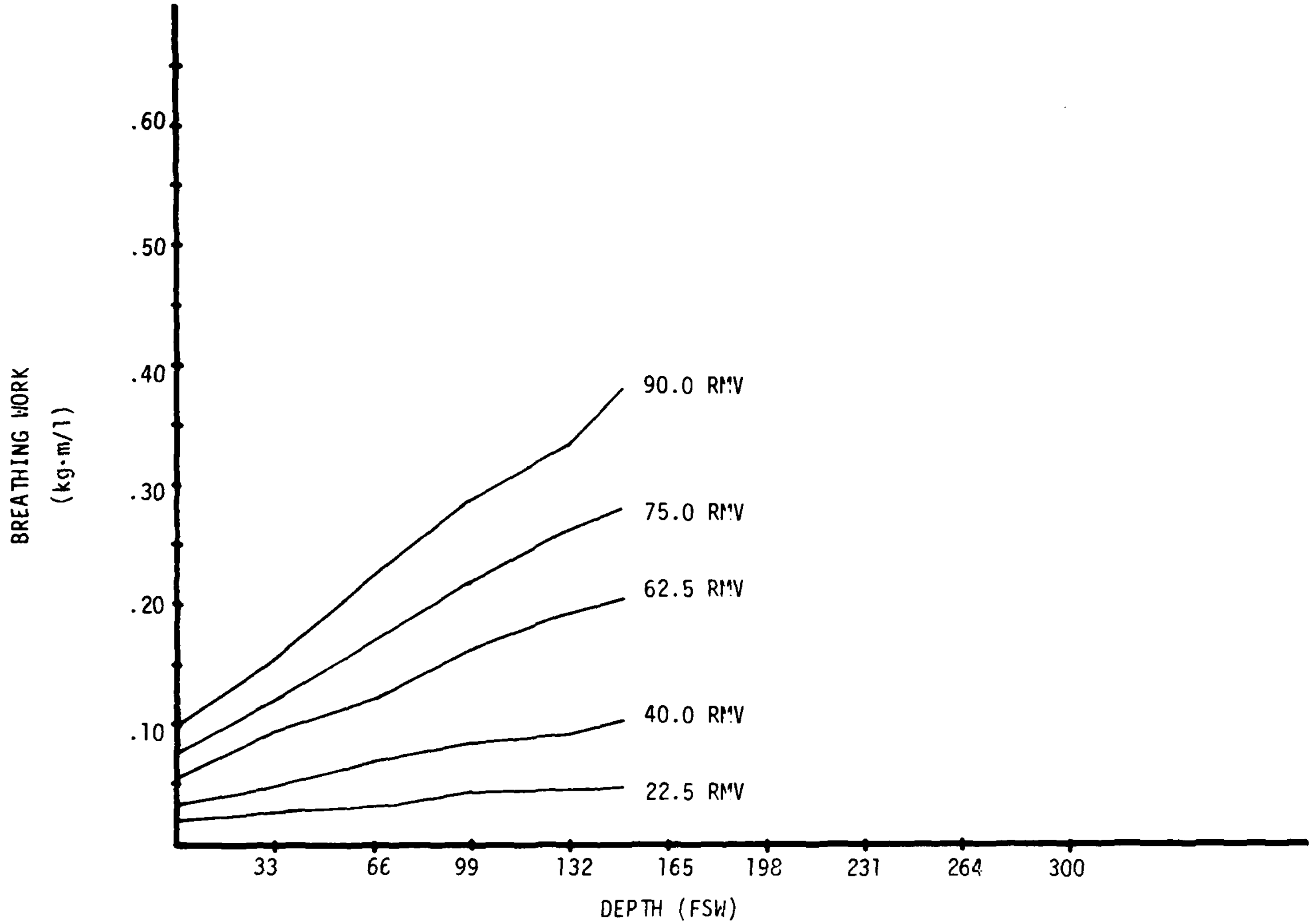

FIGURE 12 - BREATHING WORK Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Koegel Non-Return Valves
DILUENT: AIR
DILUENT SUPPLY PRESSURE: 1000 psi

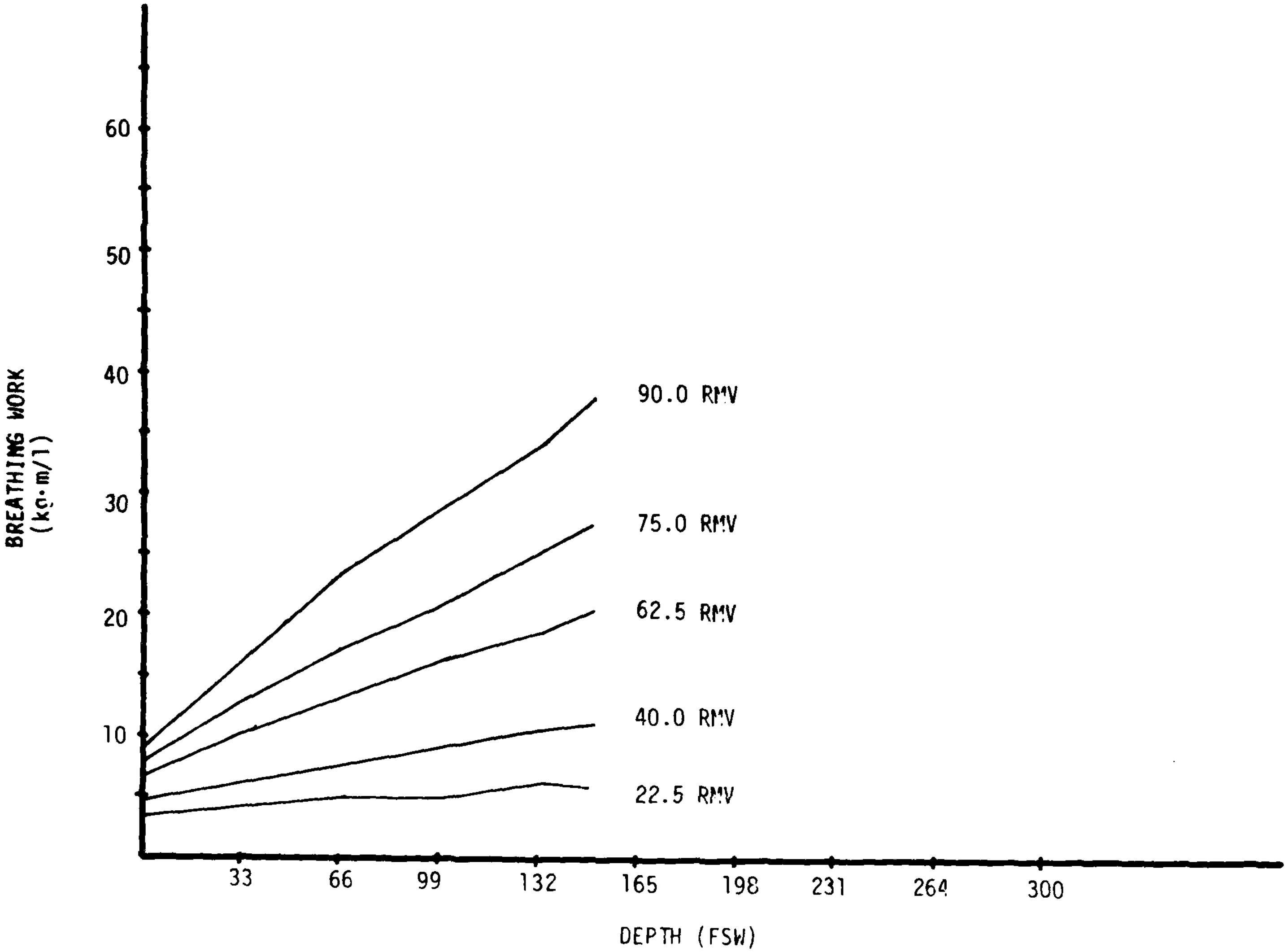

FIGURE 13 - BREATHING WORK Vs DEPTH

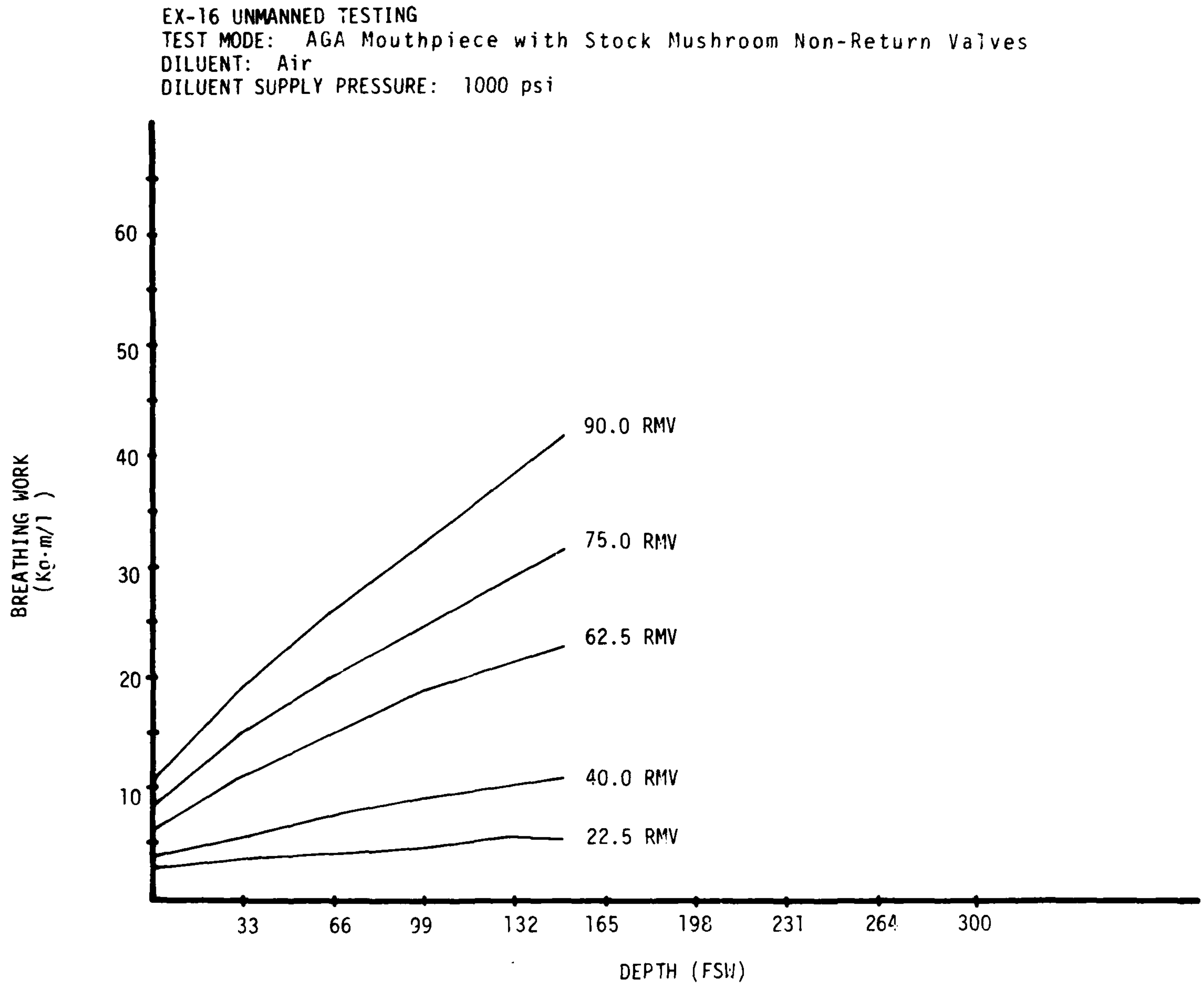

FIGURE 14 - BREATHING WORK Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Stock Mushroom Non-Return Valves
DILUENT: HeO_2
DILUENT SUPPLY PRESSURE: 1000 psi

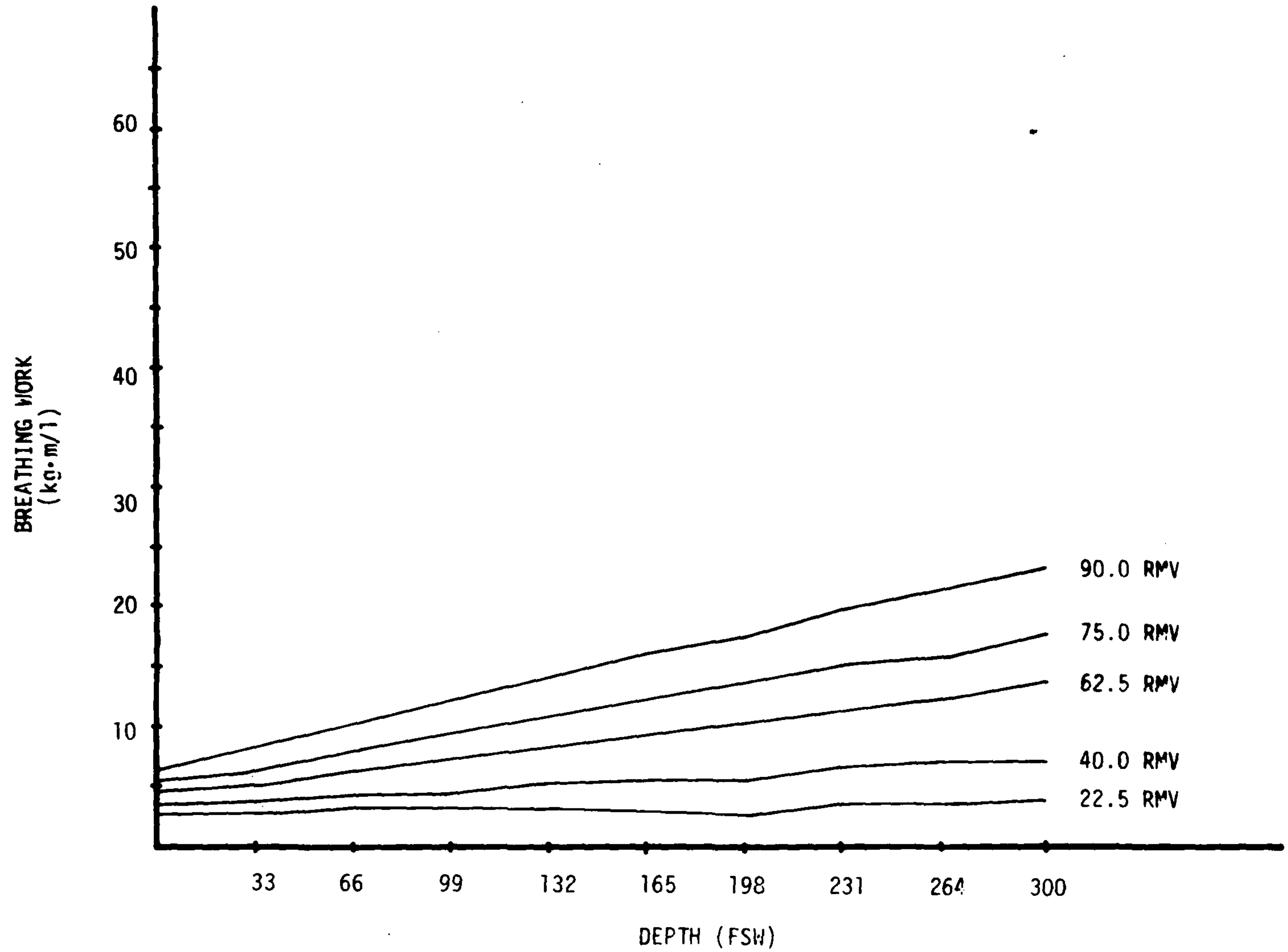

FIGURE 15 - BREATHING WORK Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Full Face Mask with Koegel Non-Return Valves
DILUENT: HeO_2
DILUENT SUPPLY PRESSURE: 1000 psi

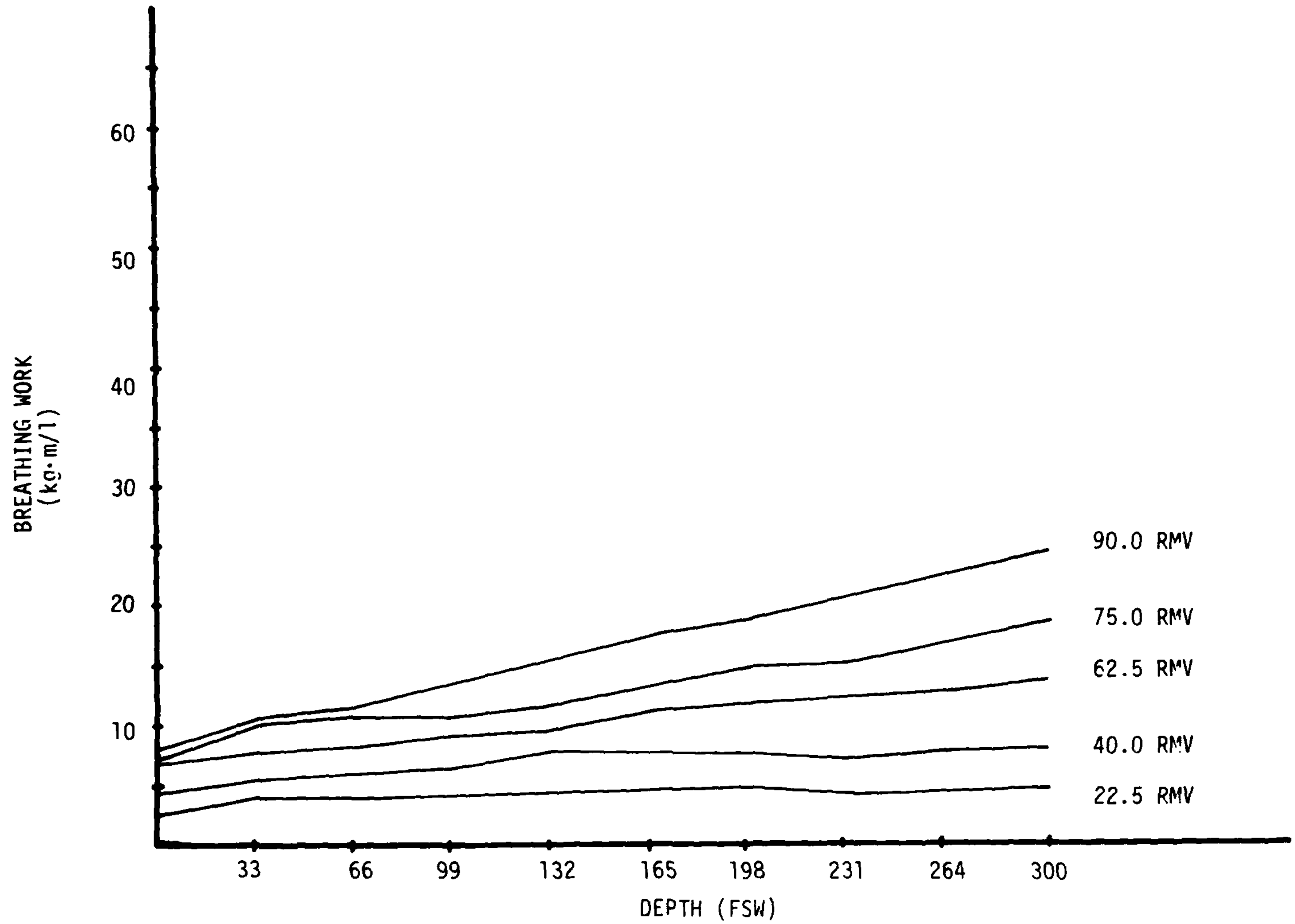

FIGURE 16 - BREATHING WORK Vs DEPTH

EX-16 UNMANNED TESTING
TEST MODE: AGA Mouthpiece with Stock Mushroom Non-Return Valves
DILUENT: HeO_2
DILUENT SUPPLY PRESSURE: 1000 psi

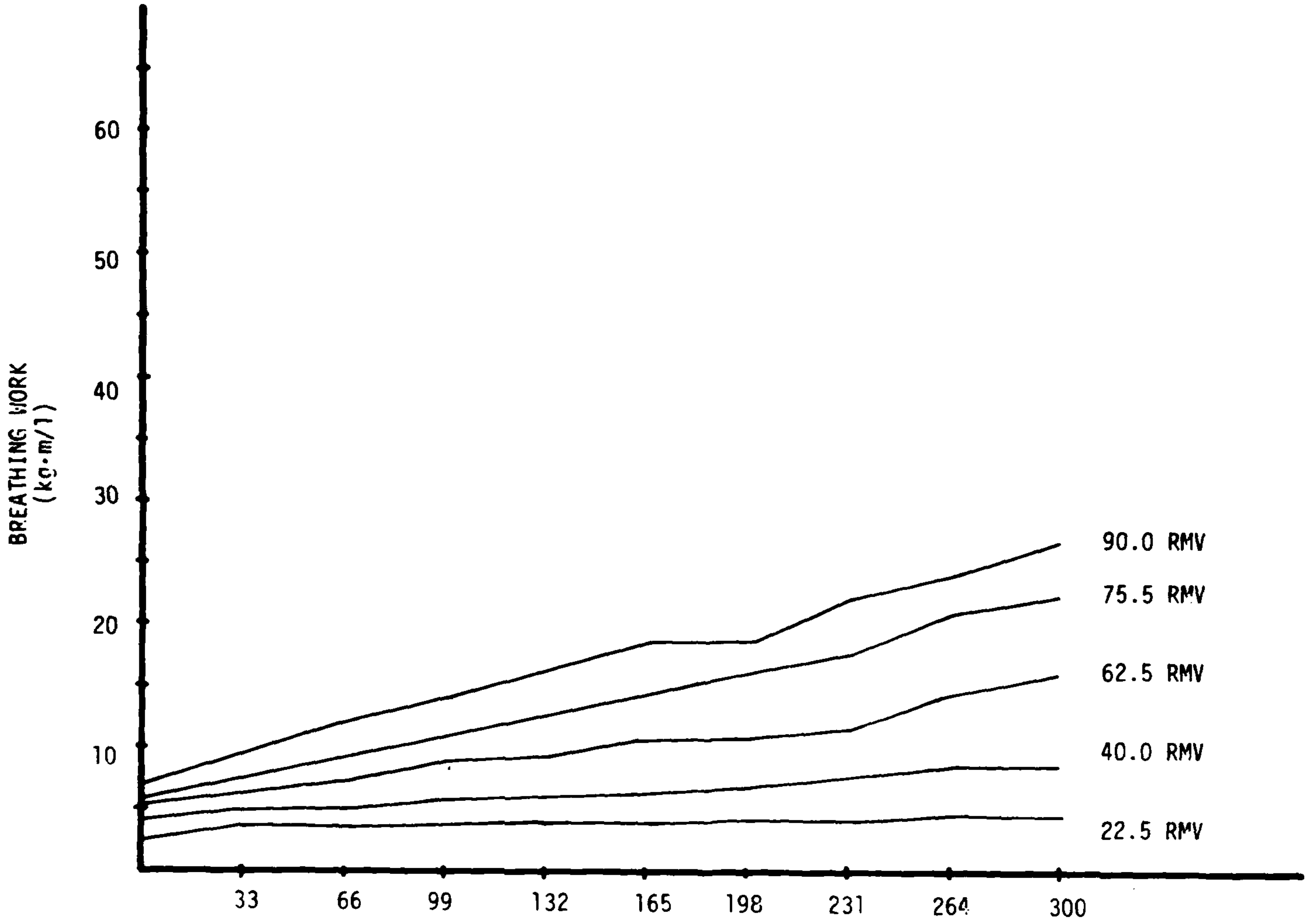

FIGURE 17- BREATHING WORK Vs DEPTH

APPENDIX E

Canister Bed Temperature Data
Figures 18 through 33

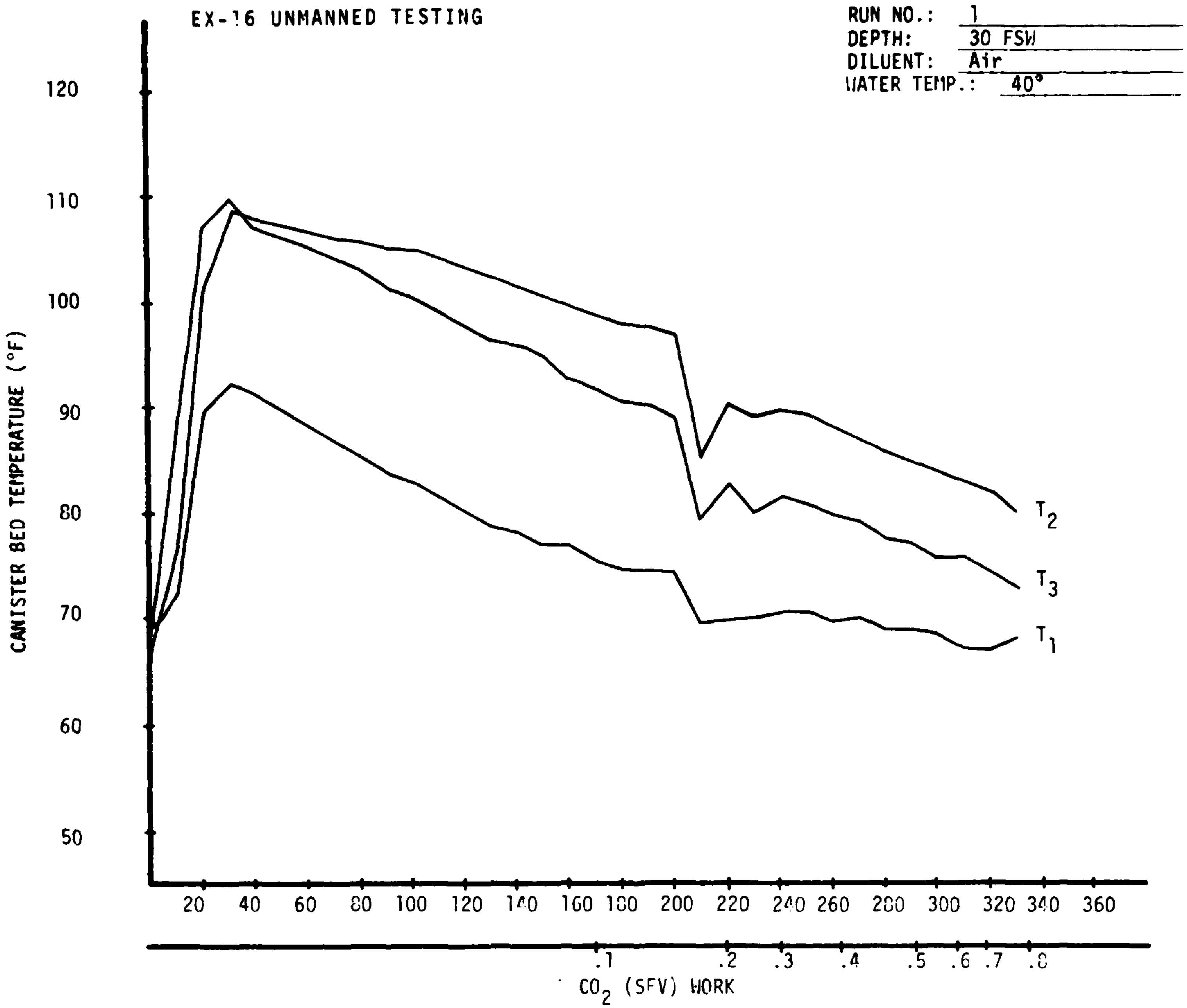

FIGURE 18 - Canister Bed Temperature Vs Time

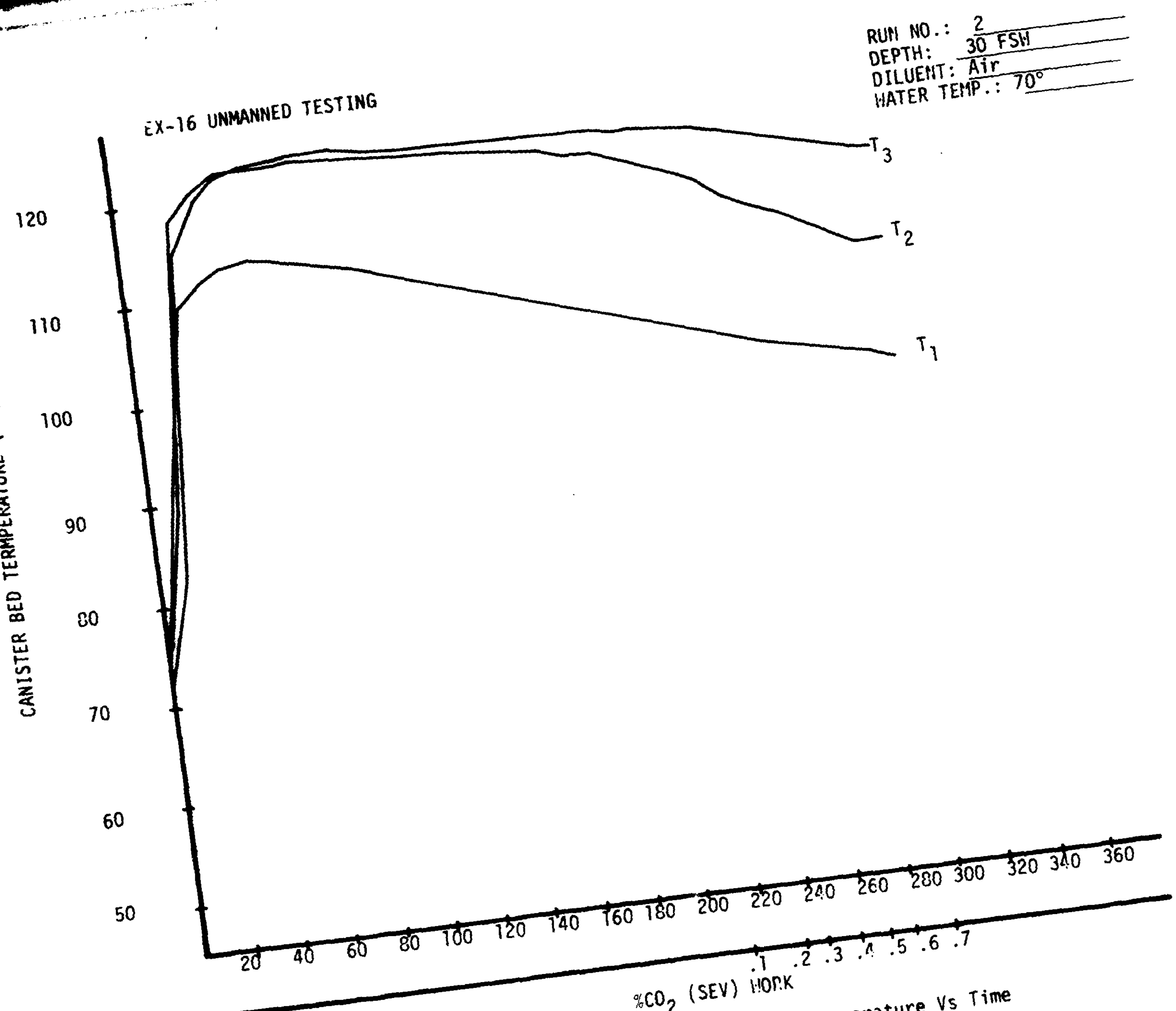

FIGURE 19 - Canister Bed Temperature Vs Time

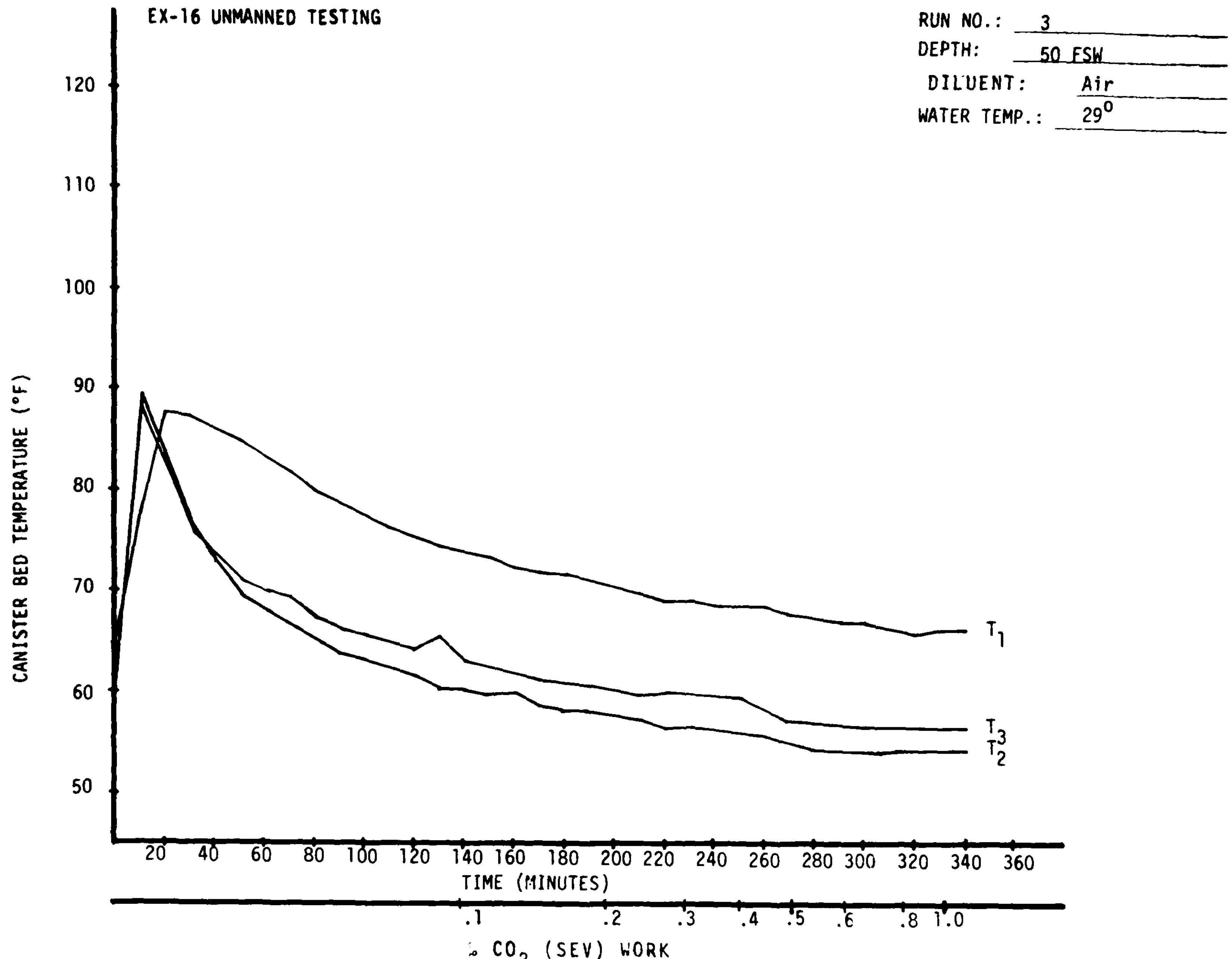

FIGURE 20 - Canister Bed Temperature Vs TIME

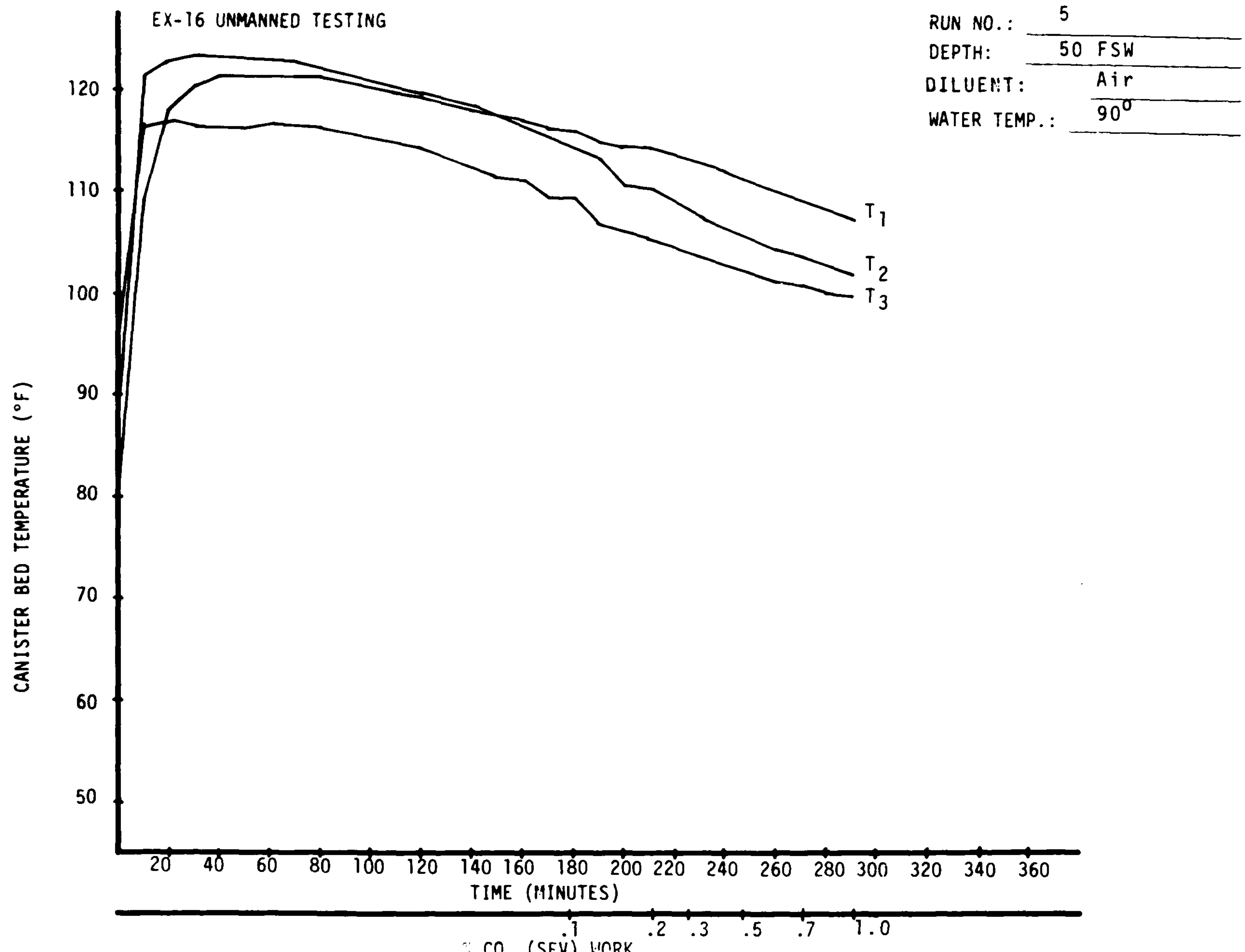

FIGURE 21 - Canister Bed Temperature Vs TIME

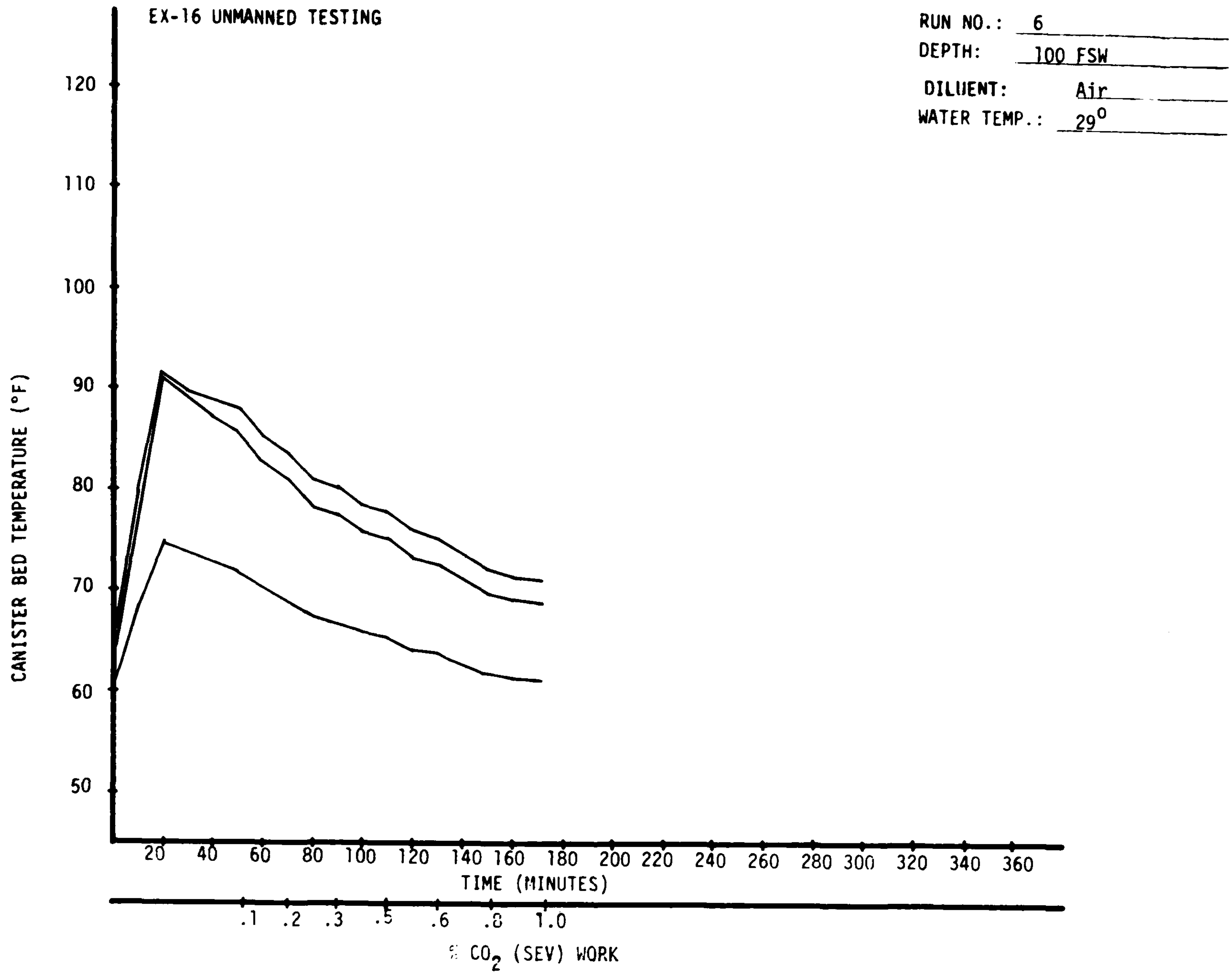

Figure 22 - Canister Bed Temperature Vs TIME

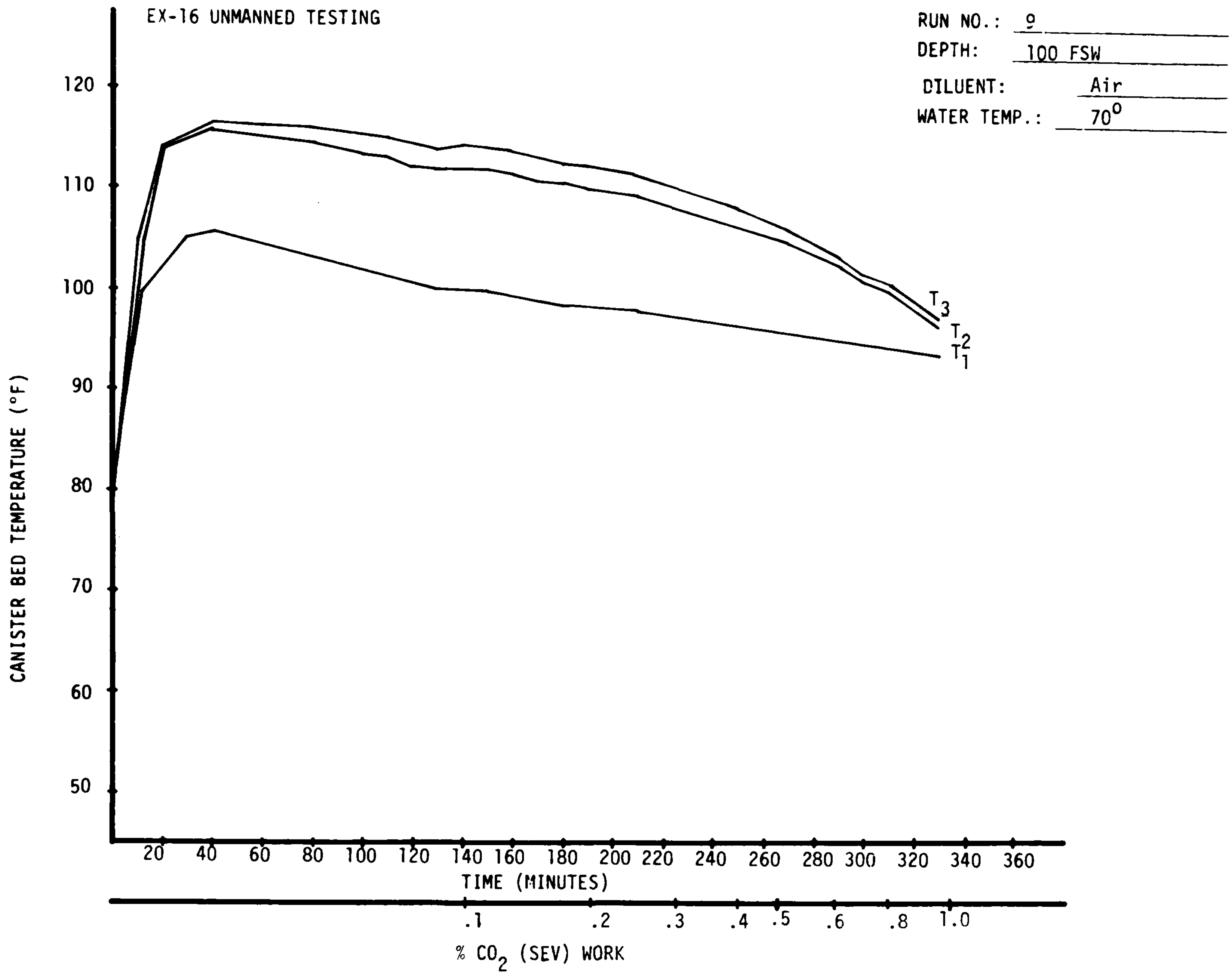

FIGURE 23 - Canister Bed Temperature Vs TIME

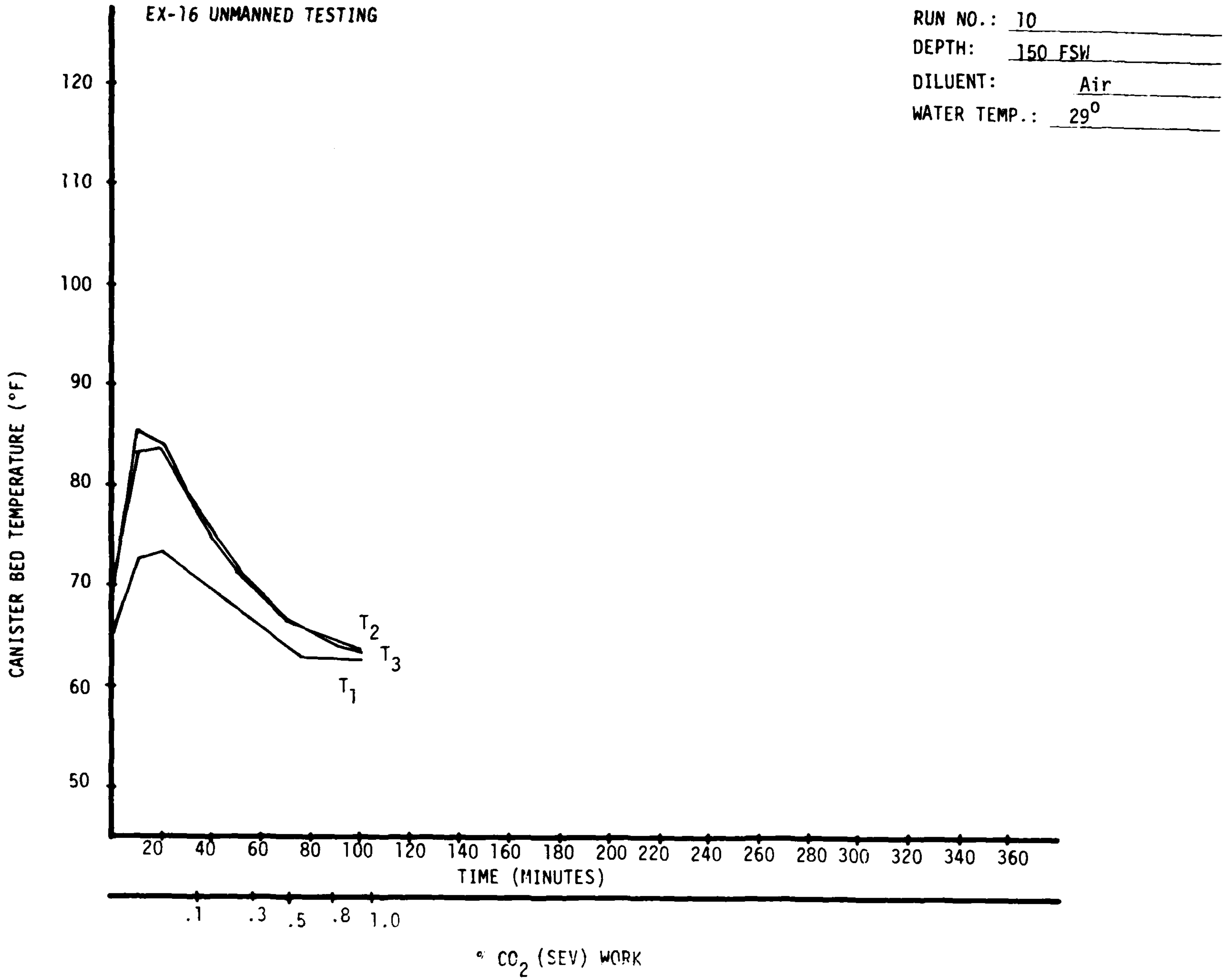

FIGURE 24 - Canister Bed Temperature Vs TIME

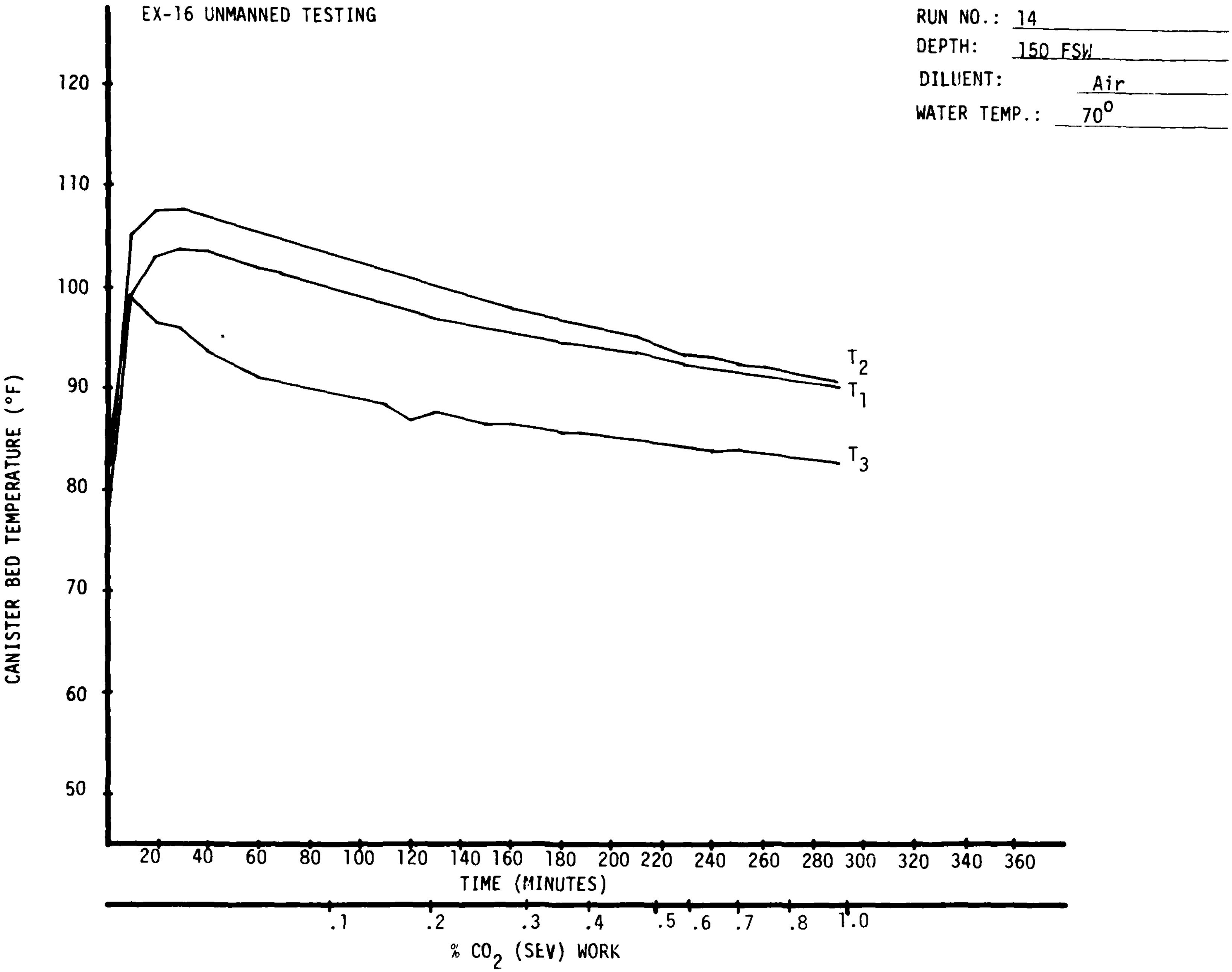

FIGURE 25 - Canister Bed Temperature Vs TIME

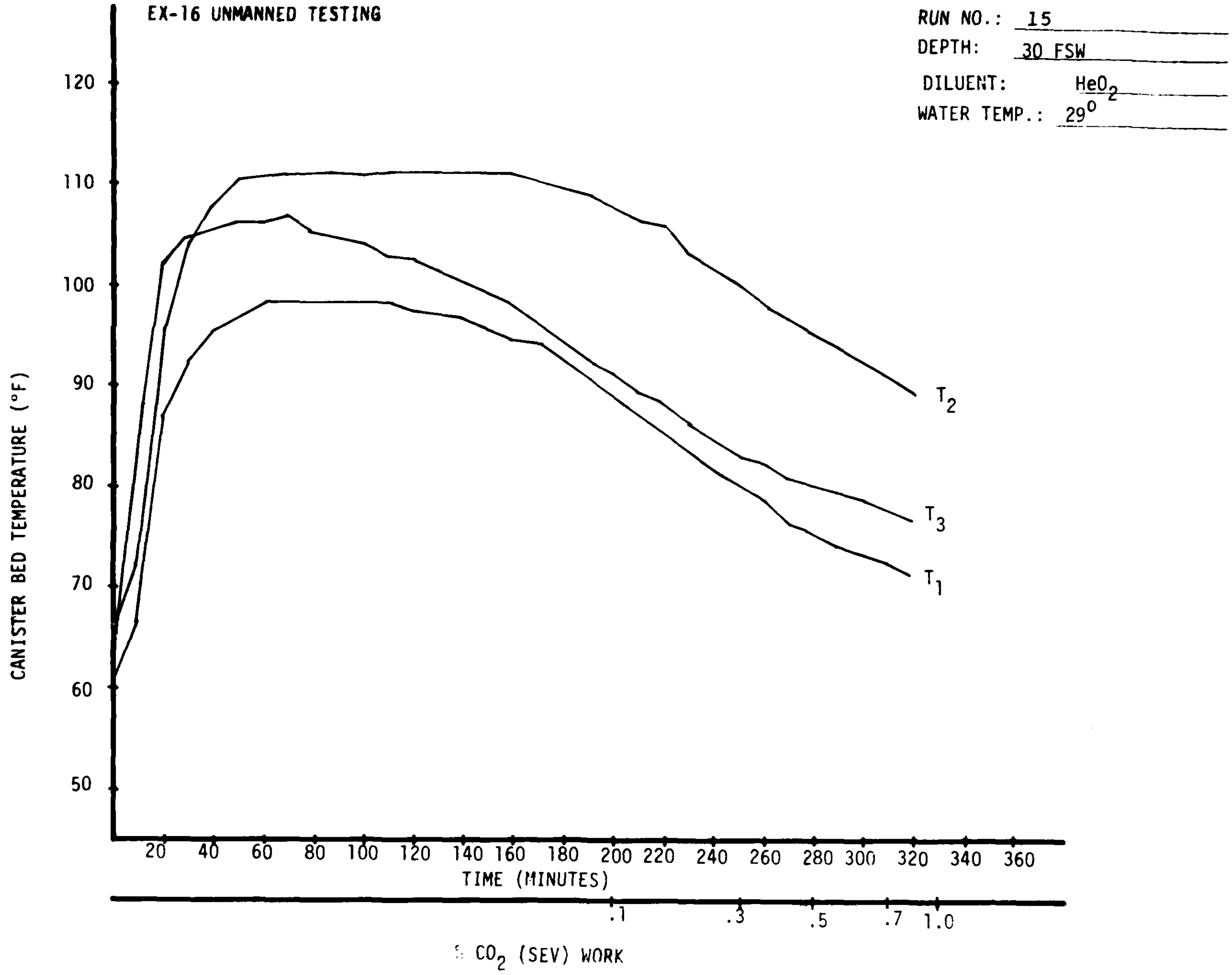

FIGURE 26 - Canister Bed Temperature Vs TIMF

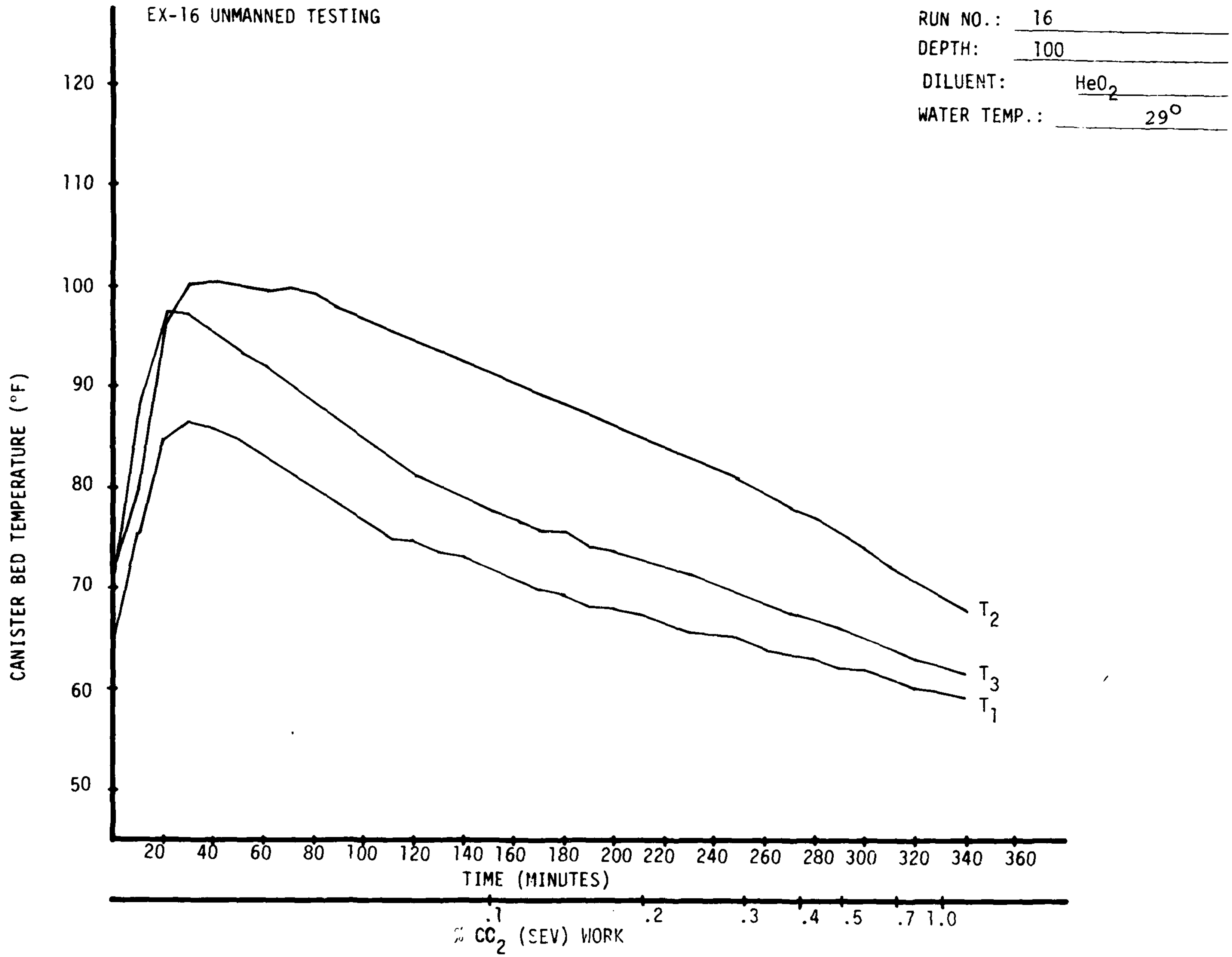

FIGURE 27 - Canister Bed Temperature Vs TIME

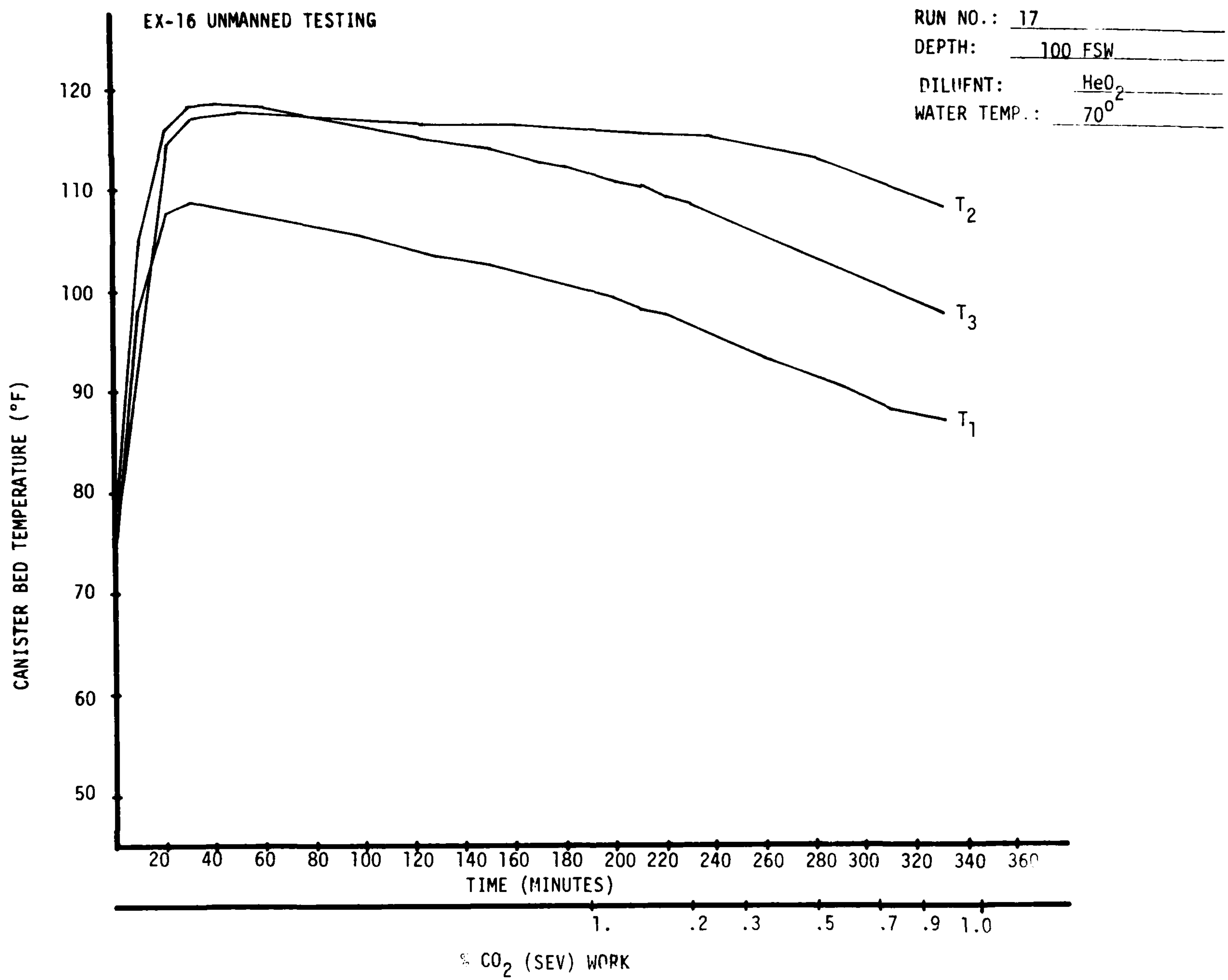

FIGURE 28- Canister Bed Temperature Vs TIME

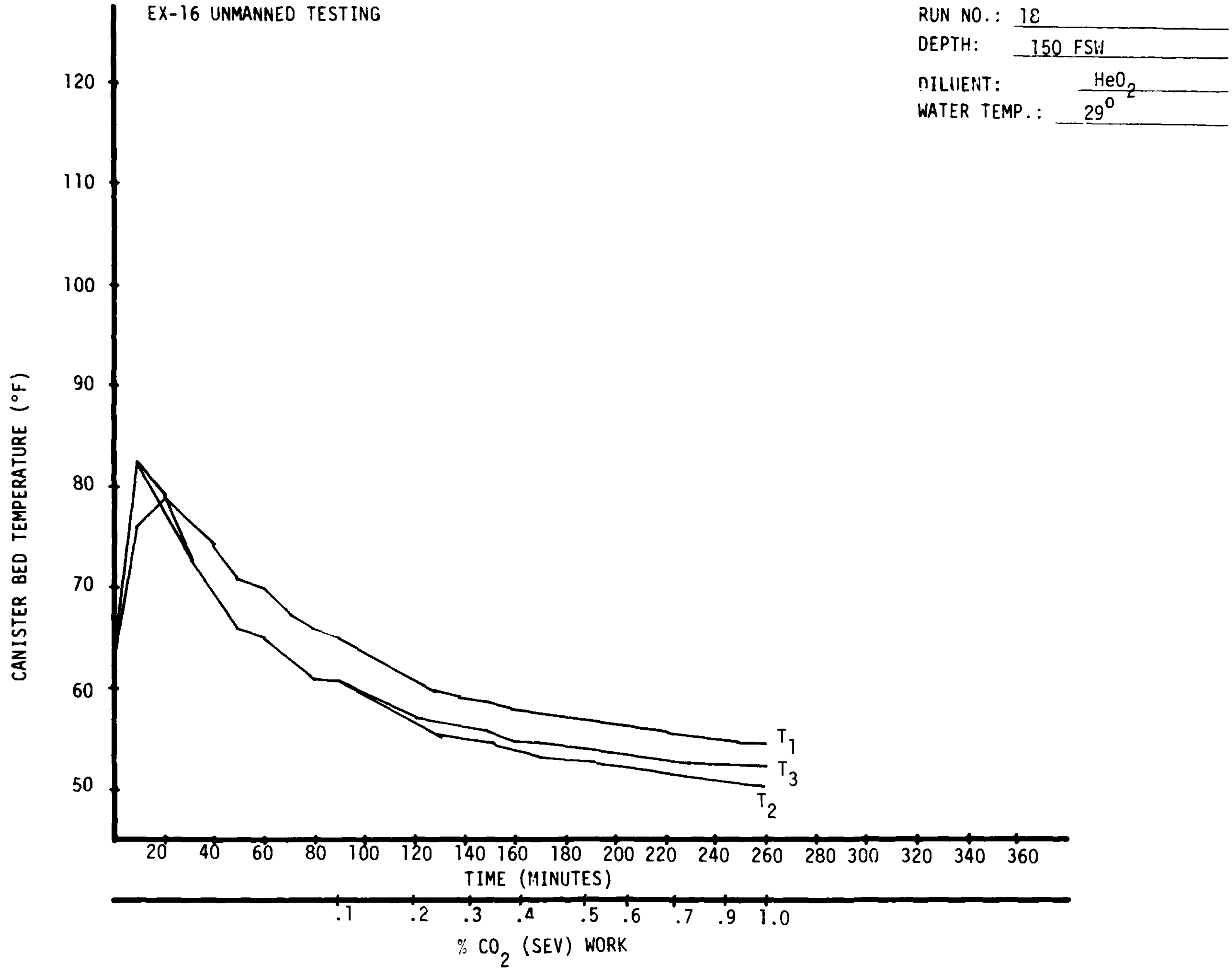

FIGURE 29 - Canister Bed Temperature Vs TIME

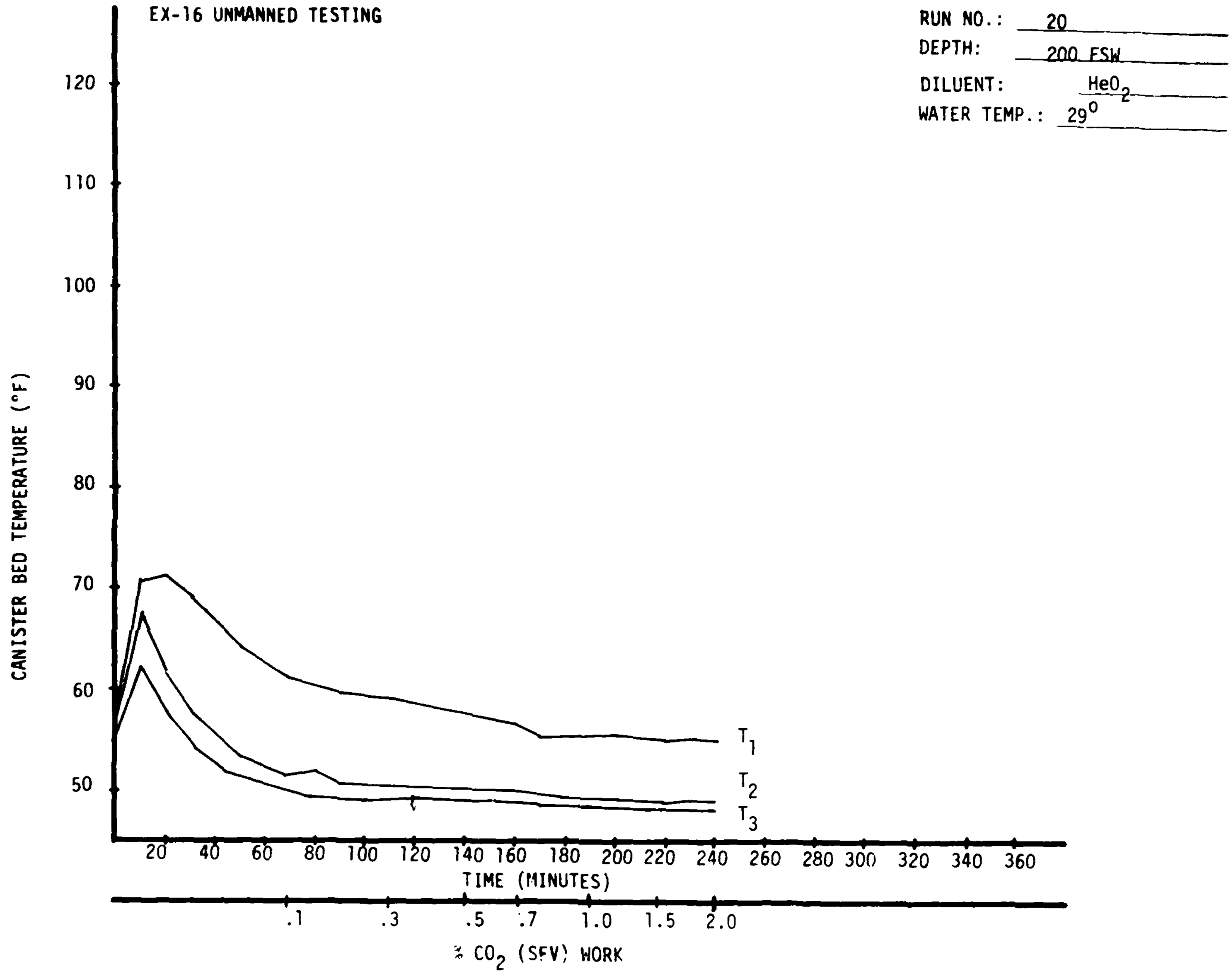

FIGURE 30 - Canister Bed Temperature Vs Time

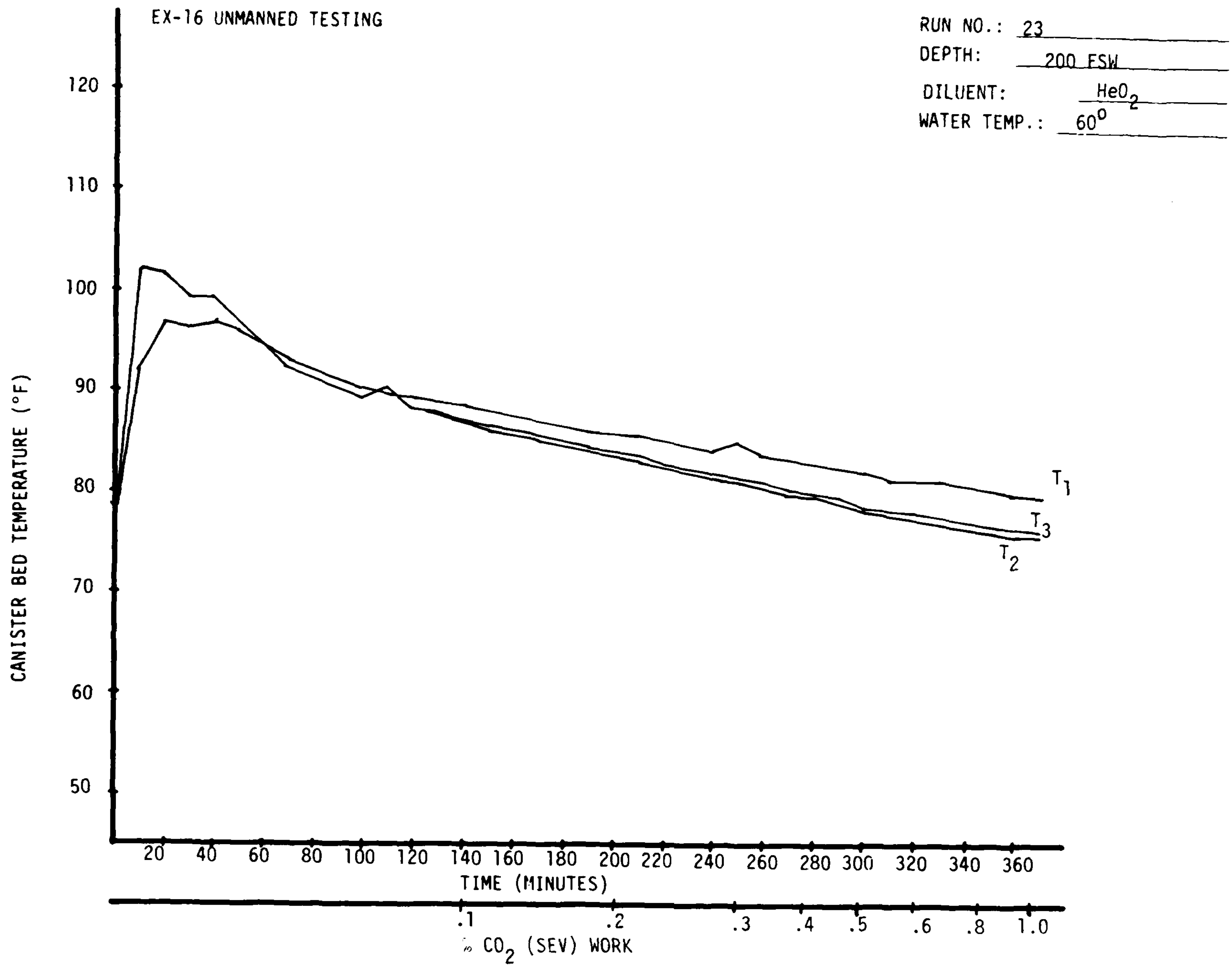

FIGURE 31 - Canister Bed Temperature Vs TIME

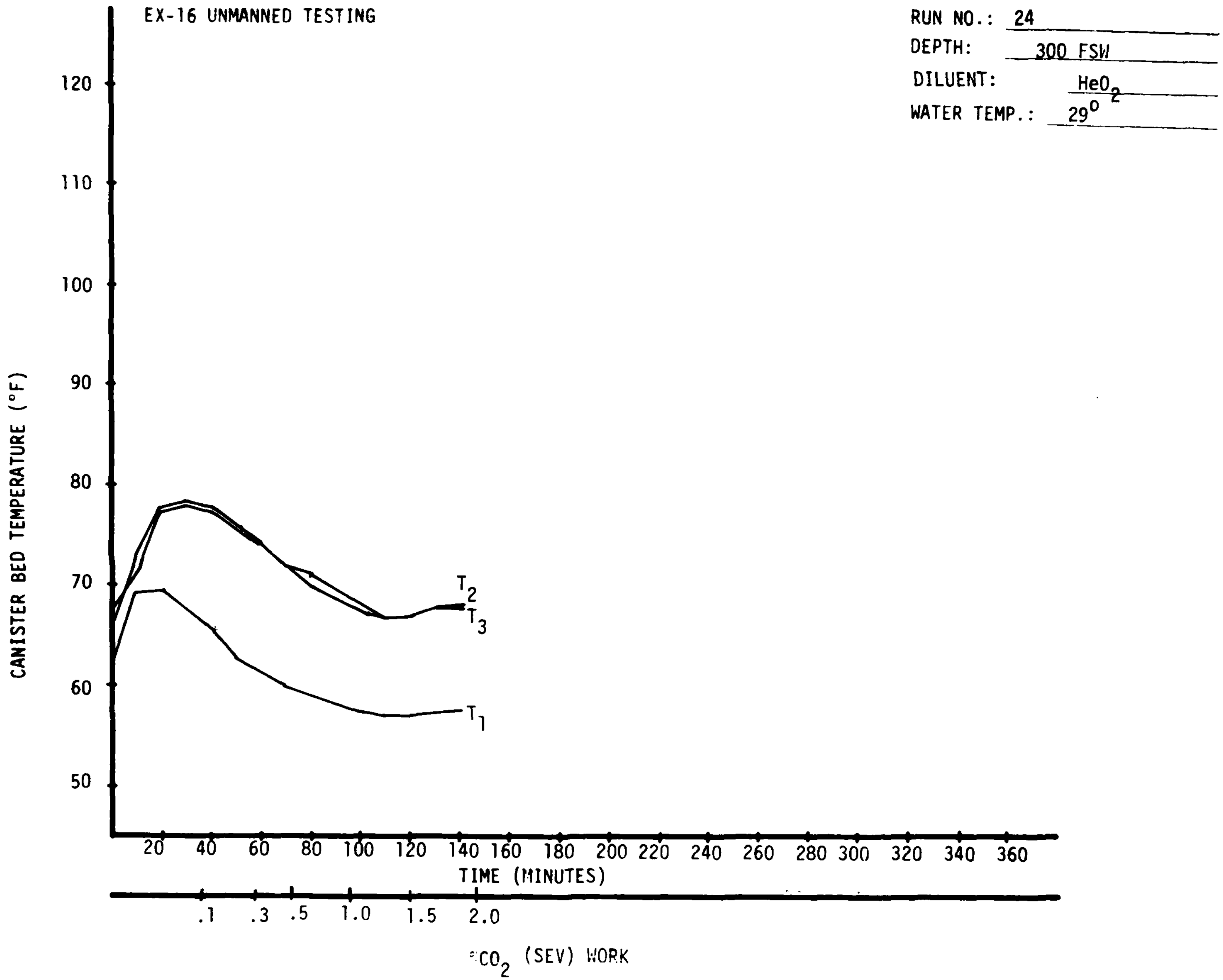

FIGURE 32 - Canister Bed Temperature Vs TIME

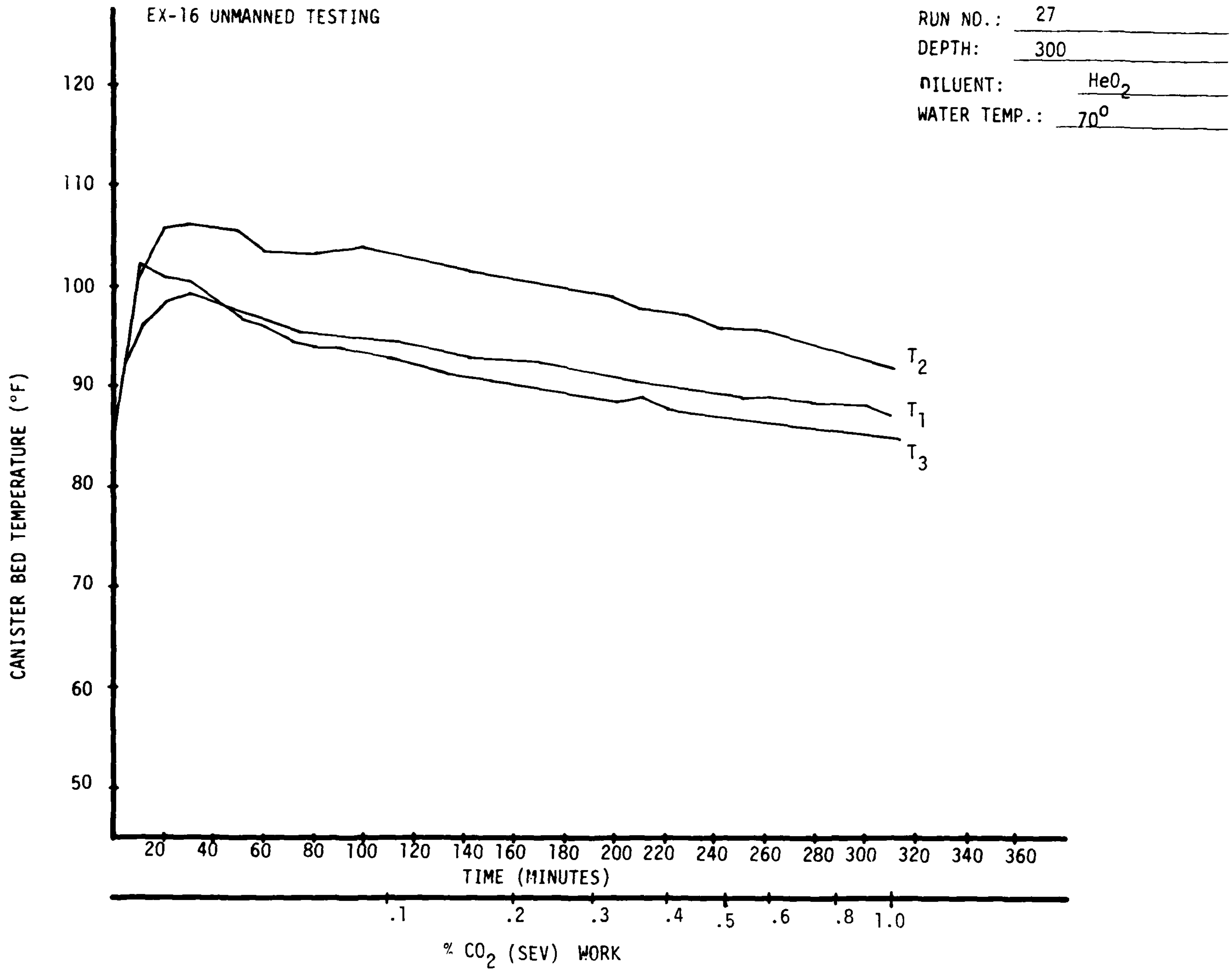

FIGURE 33 - Canister Bed Temperature Vs TIME

APPENDIX F

Canister Duration Data
Figures 34 through 60

EX-16 UNMANNED TESTING / RUN NO.: 1

DEPTH (FSW): 30 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 29 NET ABSORBENT WGT: 8# CONTENT %: 15.0

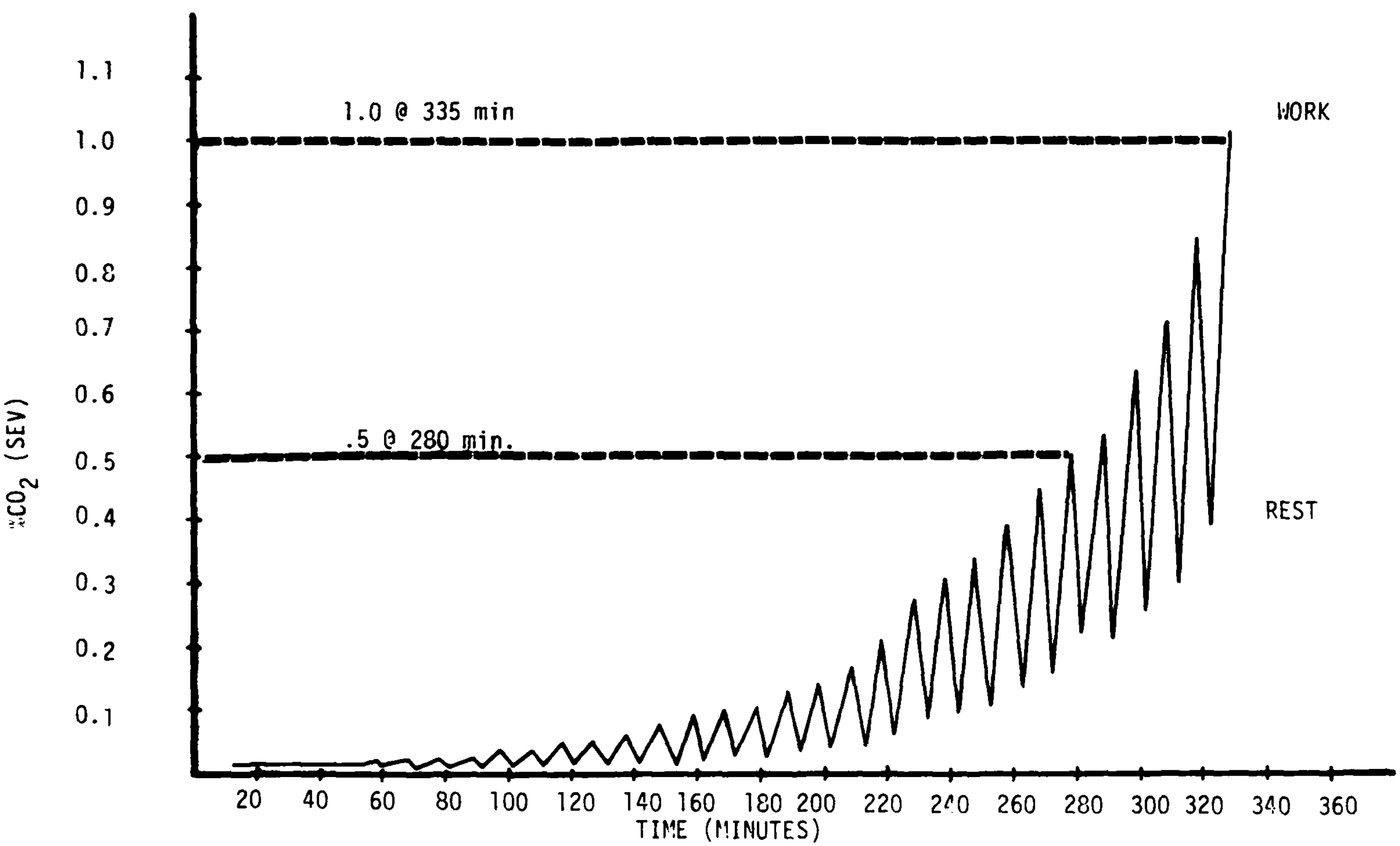

FIGURE 34- $\%CO_2$ VS TIME

EX-16 UNMANNED TESTING / RUN NO.: 2

DEPTH (FSW): 50 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 70 NET ABSORBENT WGT: 8# 2 oz CONTENT %: 14.8

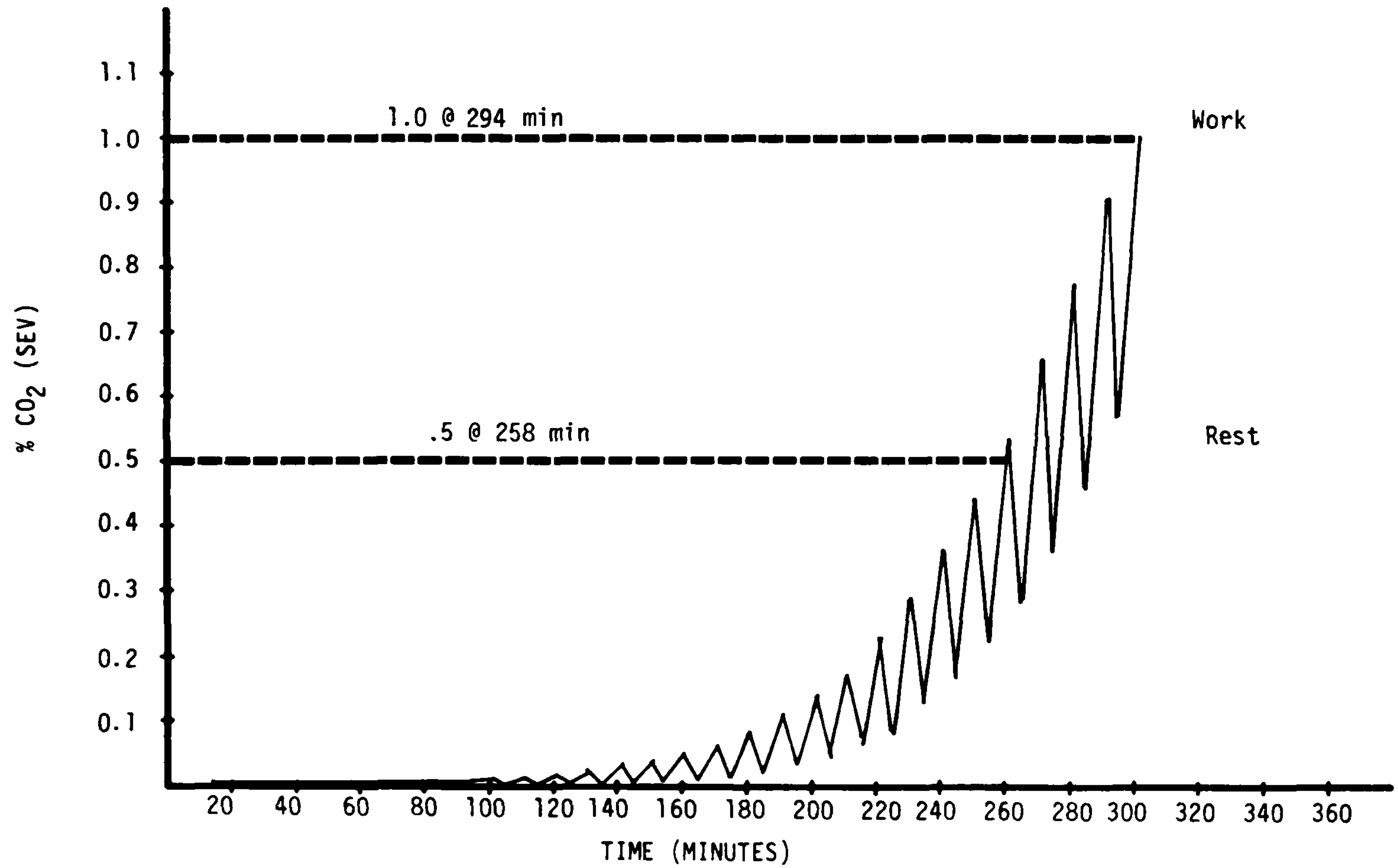

FIGURE 35 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 3

DEPTH (FSW): 50 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 29 NET ABSORBENT WGT: 8# 1 3/4 oz CONTENT %: 14.8

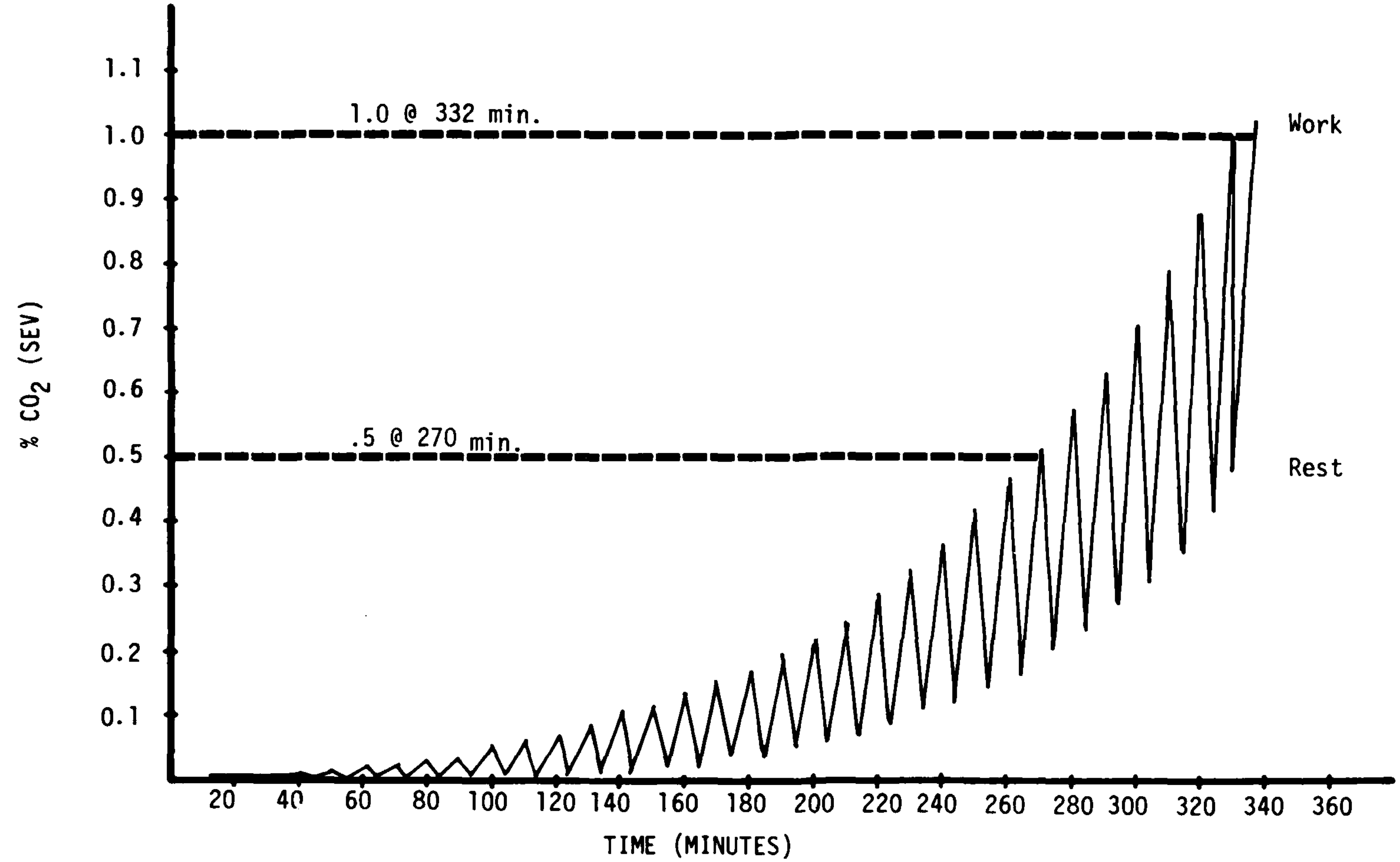

FIGURE 36 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 4

DEPTH (FSW): 50 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 40 NET ABSORBENT WGT: 8# 3/4 oz CONTENT %: 14.5

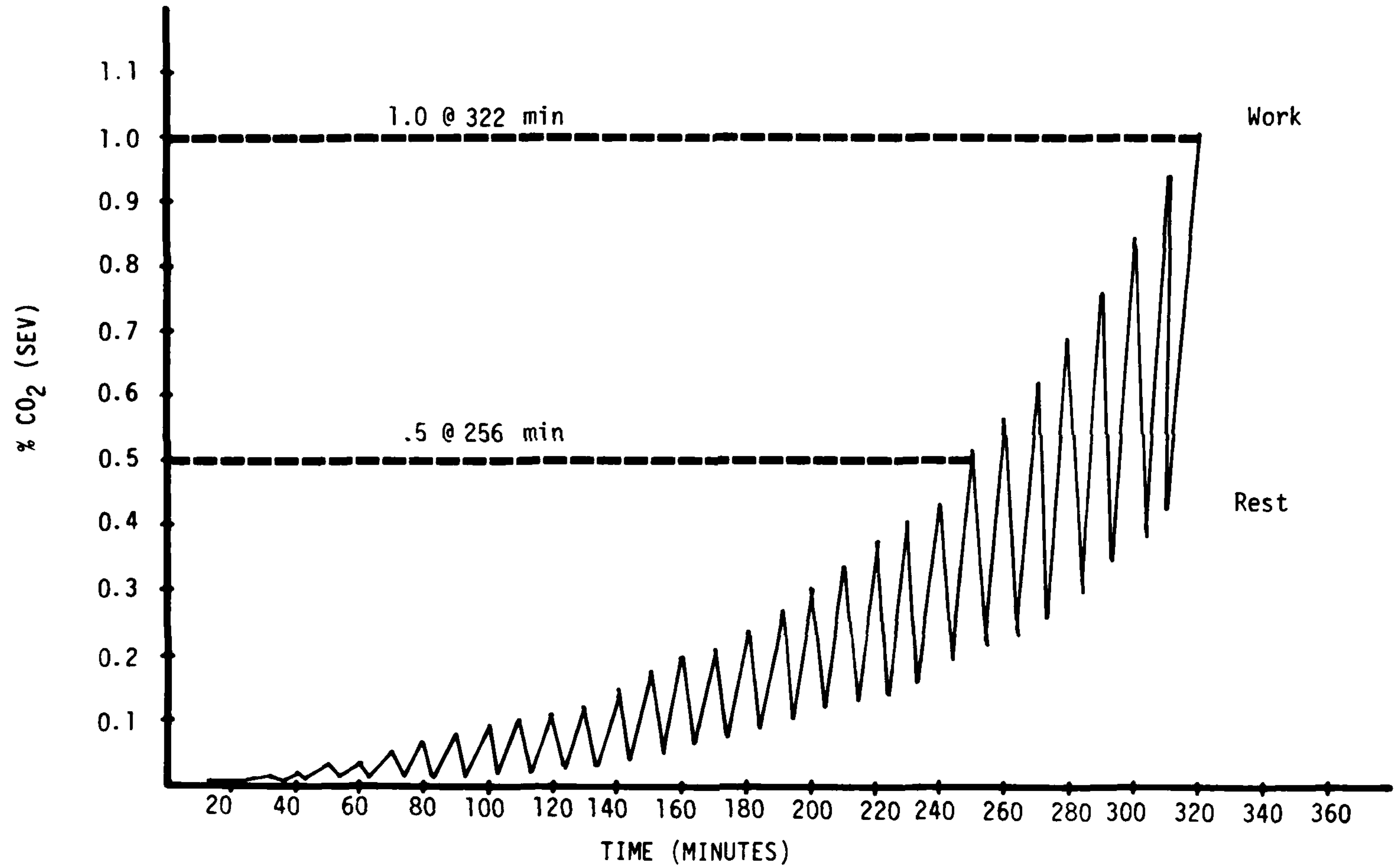

FIGURE 37 % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 5

DEPTH (FSW): 50 DILUENT: AIR ABSORBENT MOISTURE

TEMP. (°F): 90 NET ABSORBENT WGT: 8# CONTENT %: 13.99

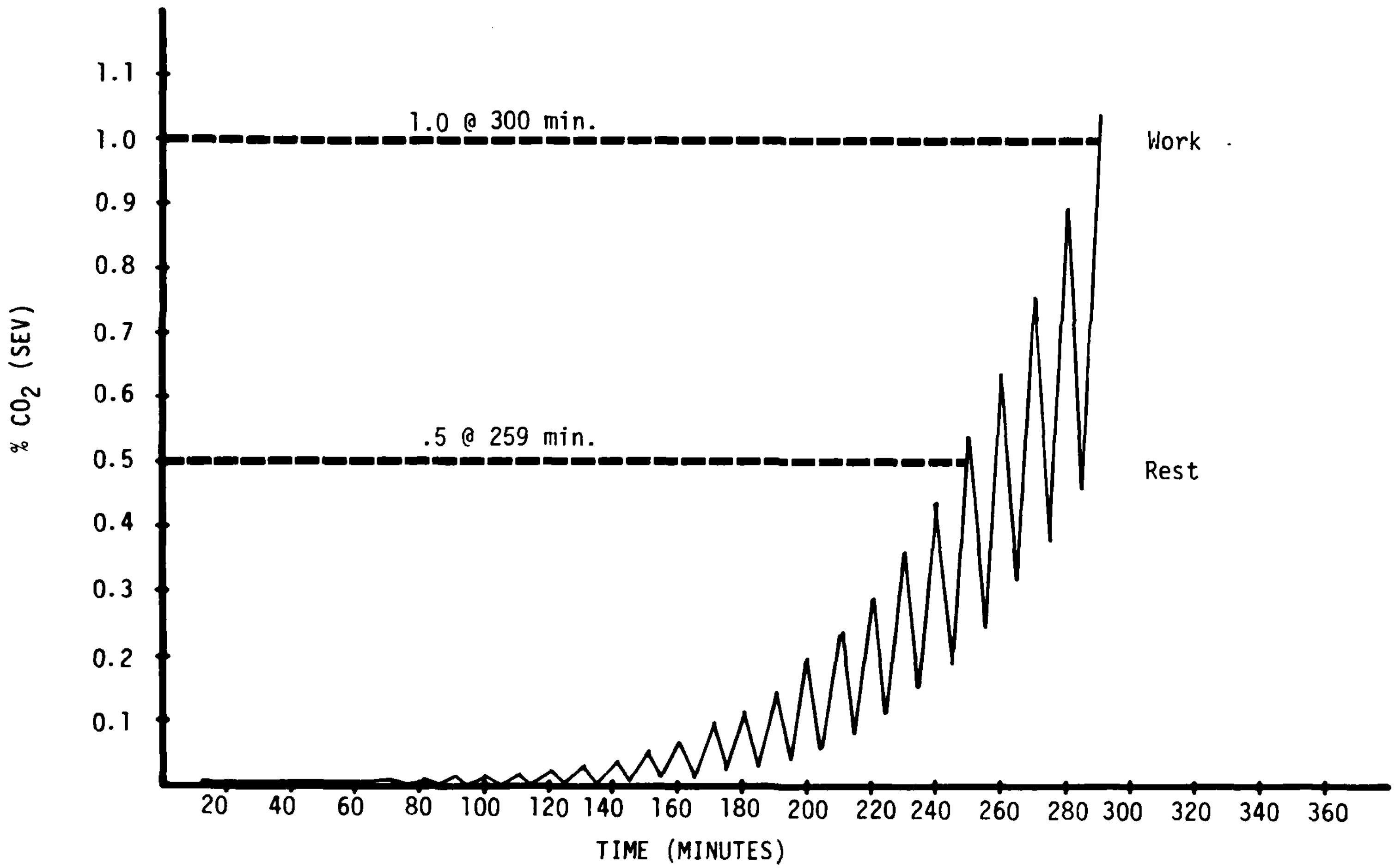

FIGURE 38- % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 6

DEPTH (FSW): 100 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 29 NET ABSORBENT WGT: 8# CONTENT %: 15.0

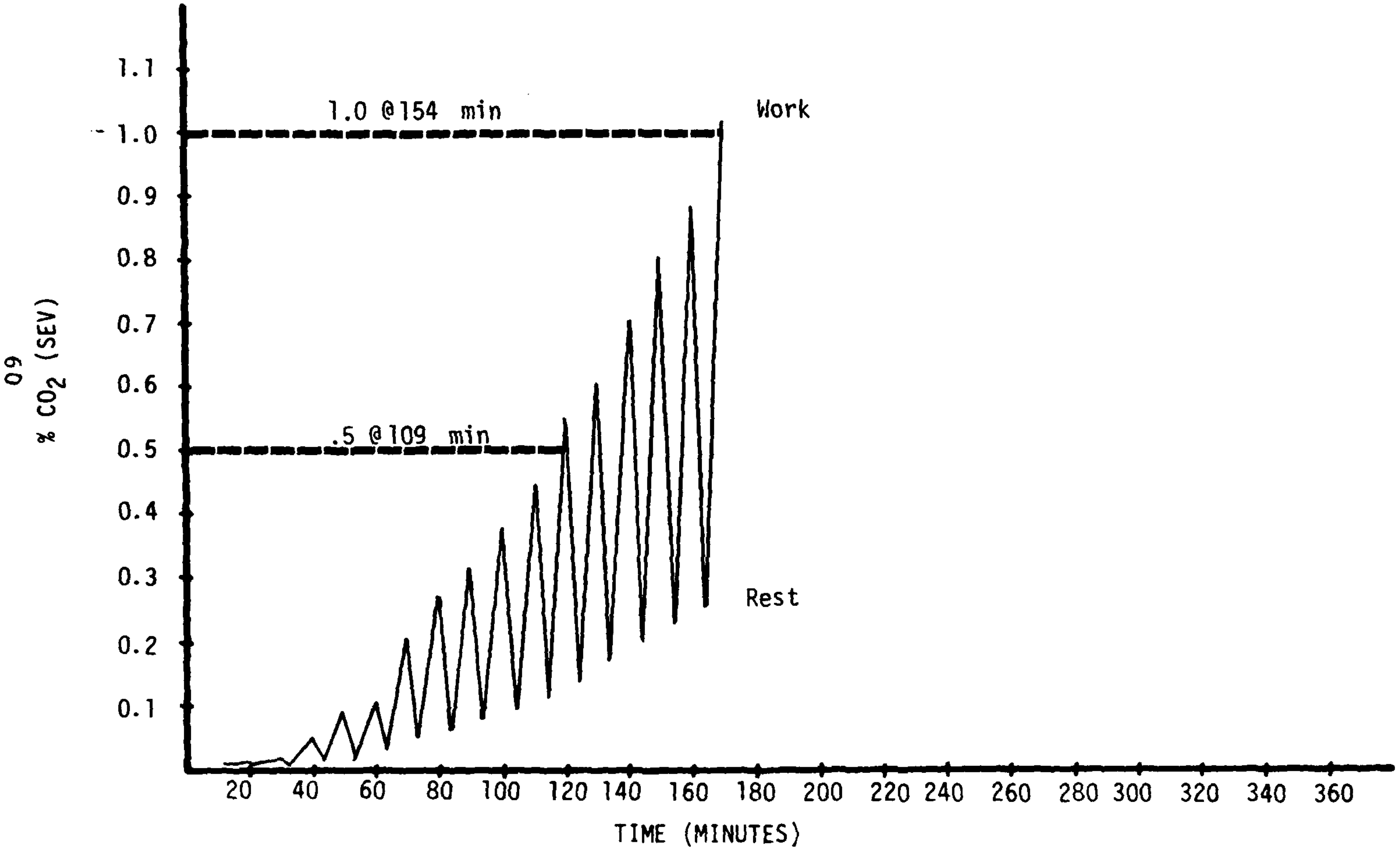

FIGURE 39 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 7

DEPTH (FSW): 100 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 40 NET ABSORBENT WGT: 8# 1 oz CONTENT %: 14.8

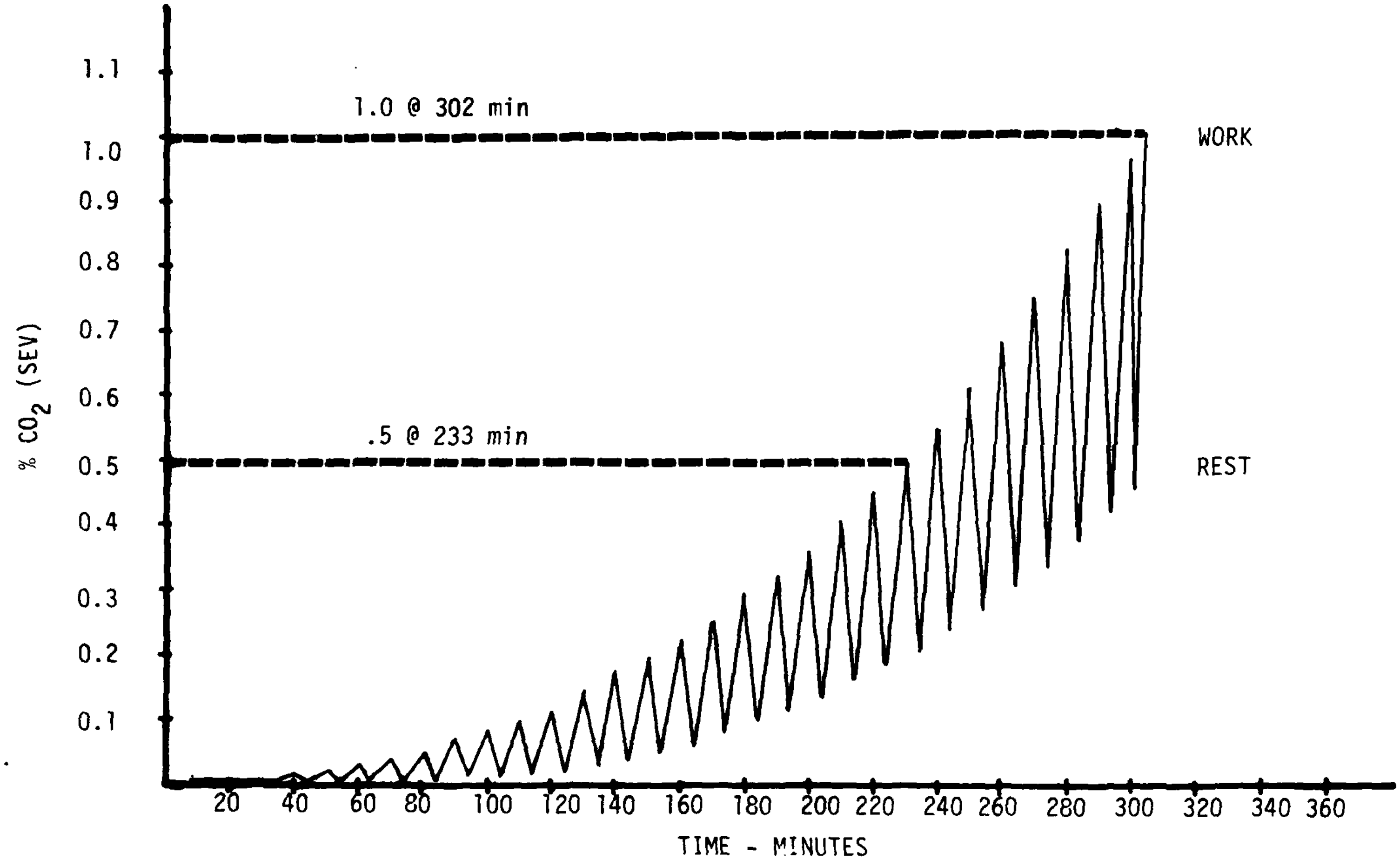

FIGURE 40 - % CO_2 Vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 8
DEPTH (FSW): 100 DILUENT: AIR ABSORBENT MOISTURE
TEMP. (°F): 50 NET ABSORBENT WGT: 8# 4 3/4 oz CONTENT %: 14.8

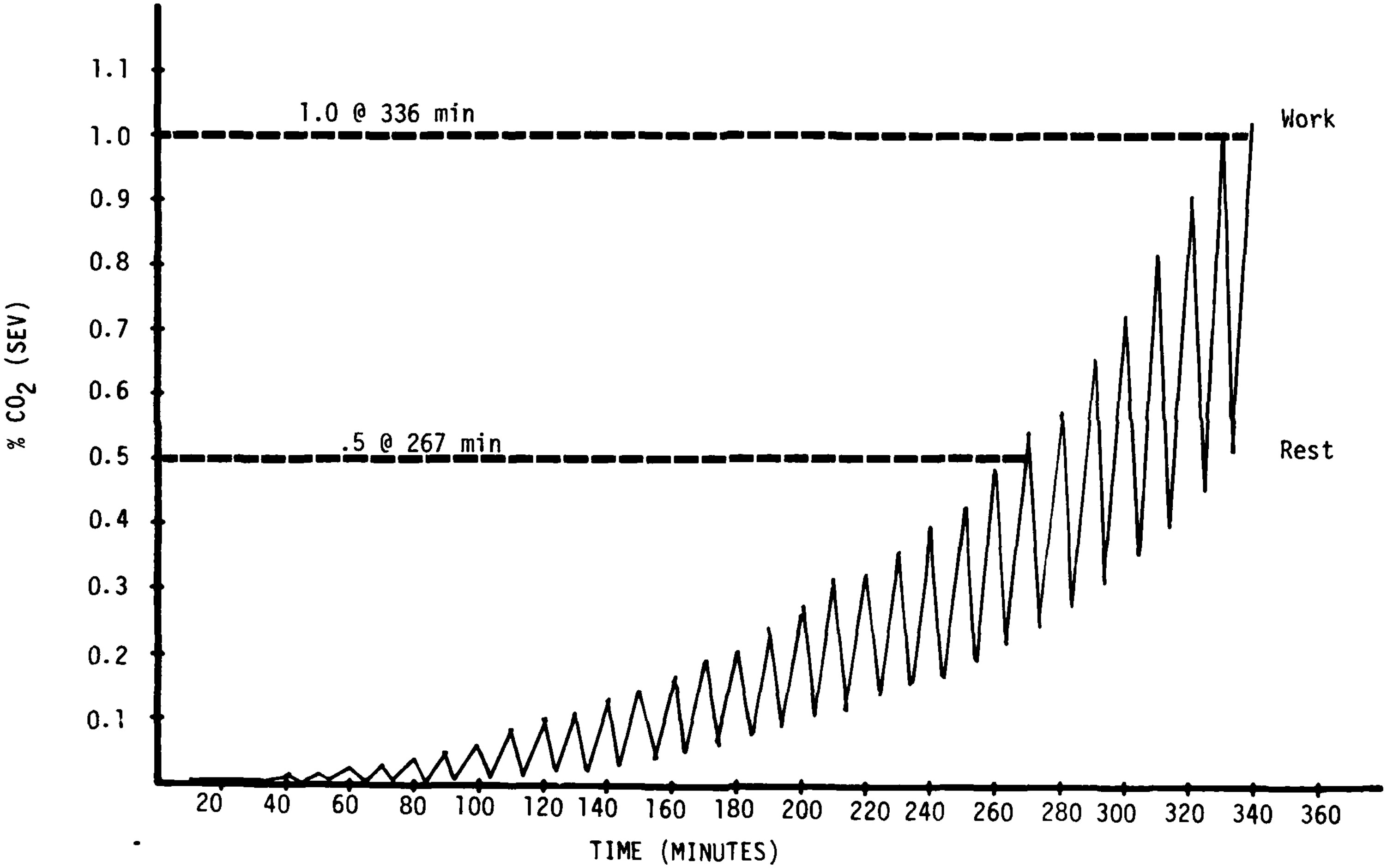

FIGURE 41- % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 9

DEPTH (FSW): 100 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 70 NET ABSORBENT WGT: 8 # 3 3/4 oz CONTENT %: 14.6

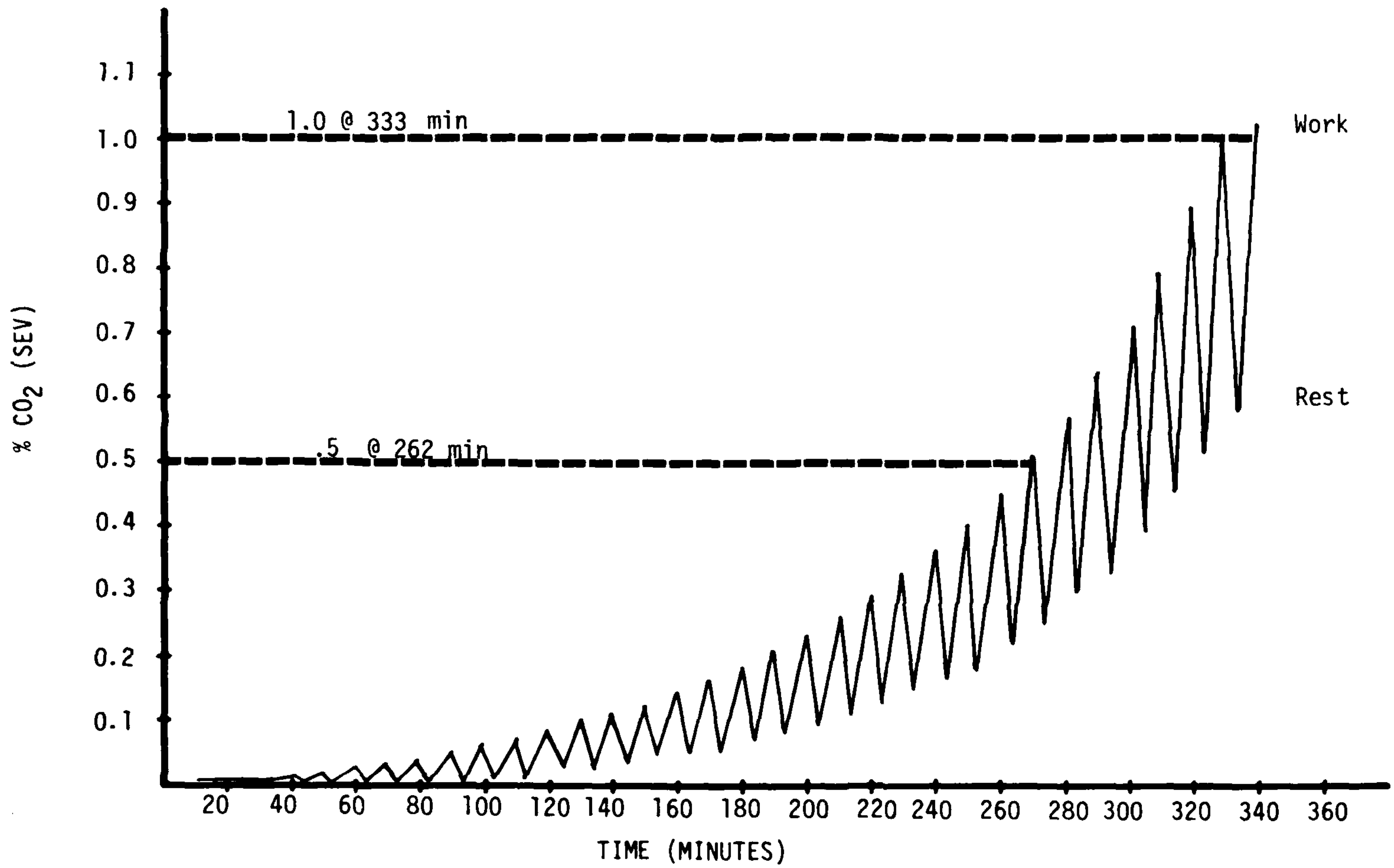

FIGURE 42 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 11

DEPTH (FSW): 150 DILUENT HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 40 NET ABSORBENT WGT: 7# 13 5/8 oz CONTENT %: 14.8

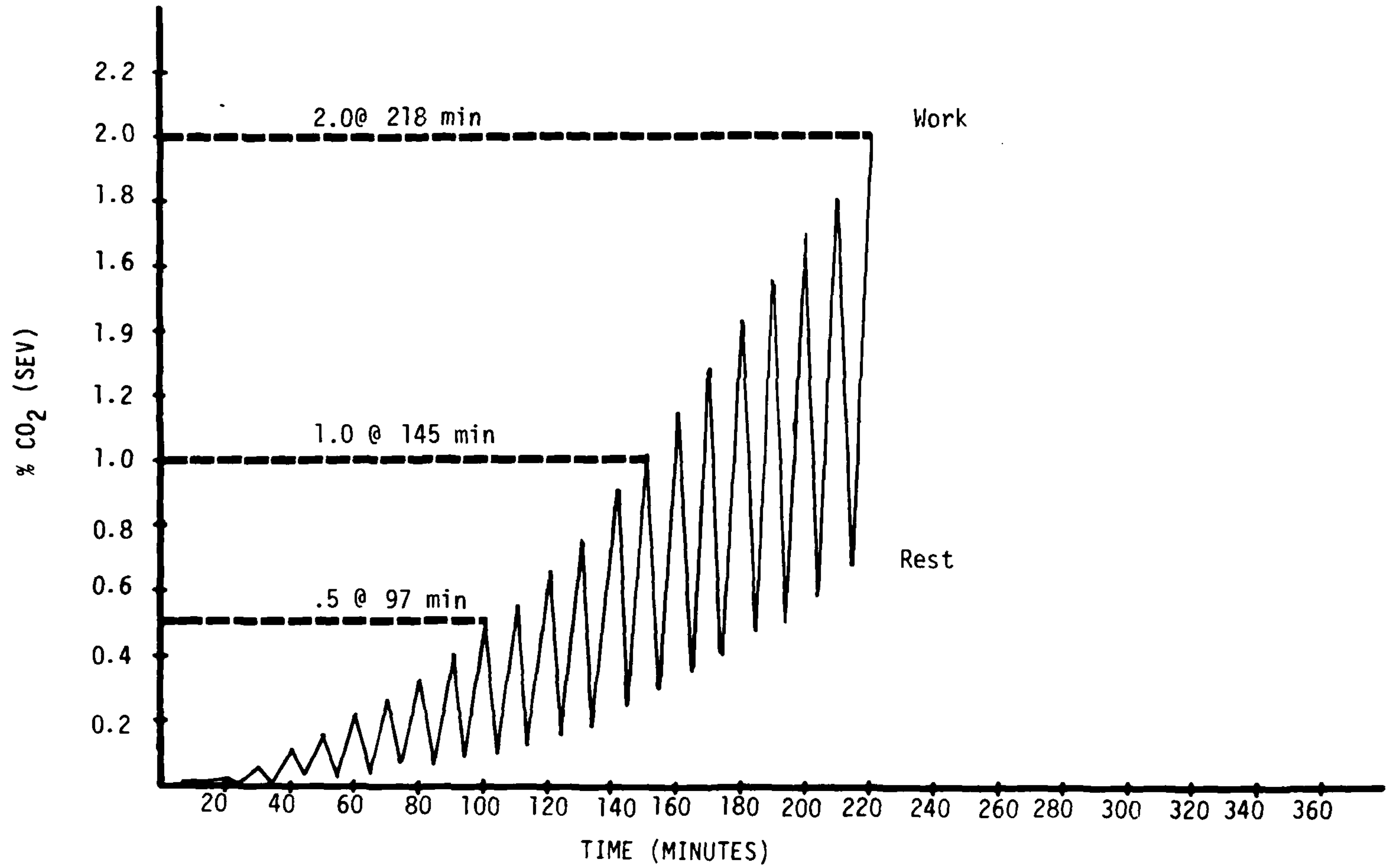

FIGURE 43 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 10

DEPTH (FSW): 150 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 40 NET ABSORBENT WGT: 7# 14 3/4 oz CONTENT %: 14.8

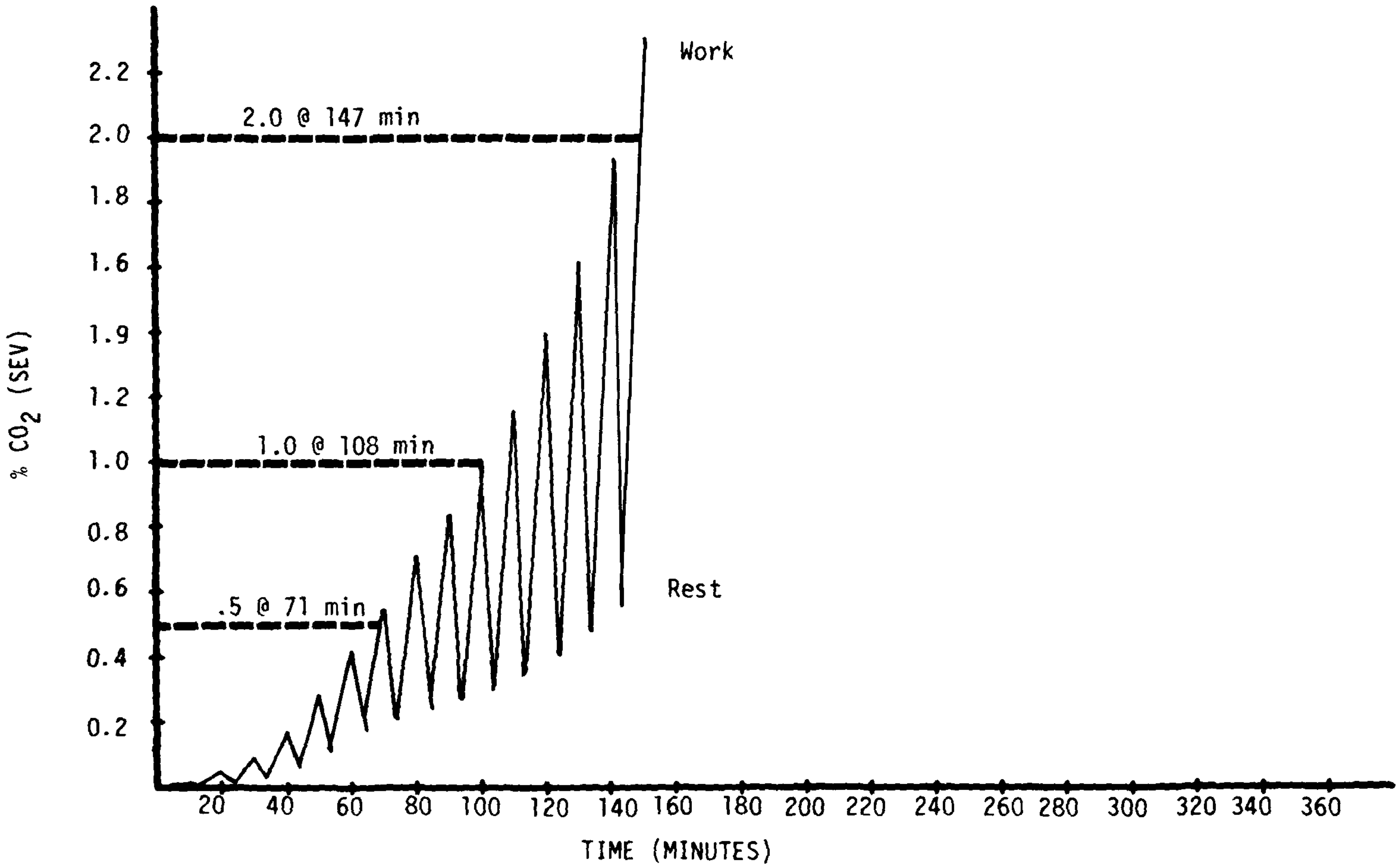

FIGURE 44 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 12

DEPTH (FSW): 150 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 50 NET ABSORBENT WGT: 8# 1 oz CONTENT %: 14.8

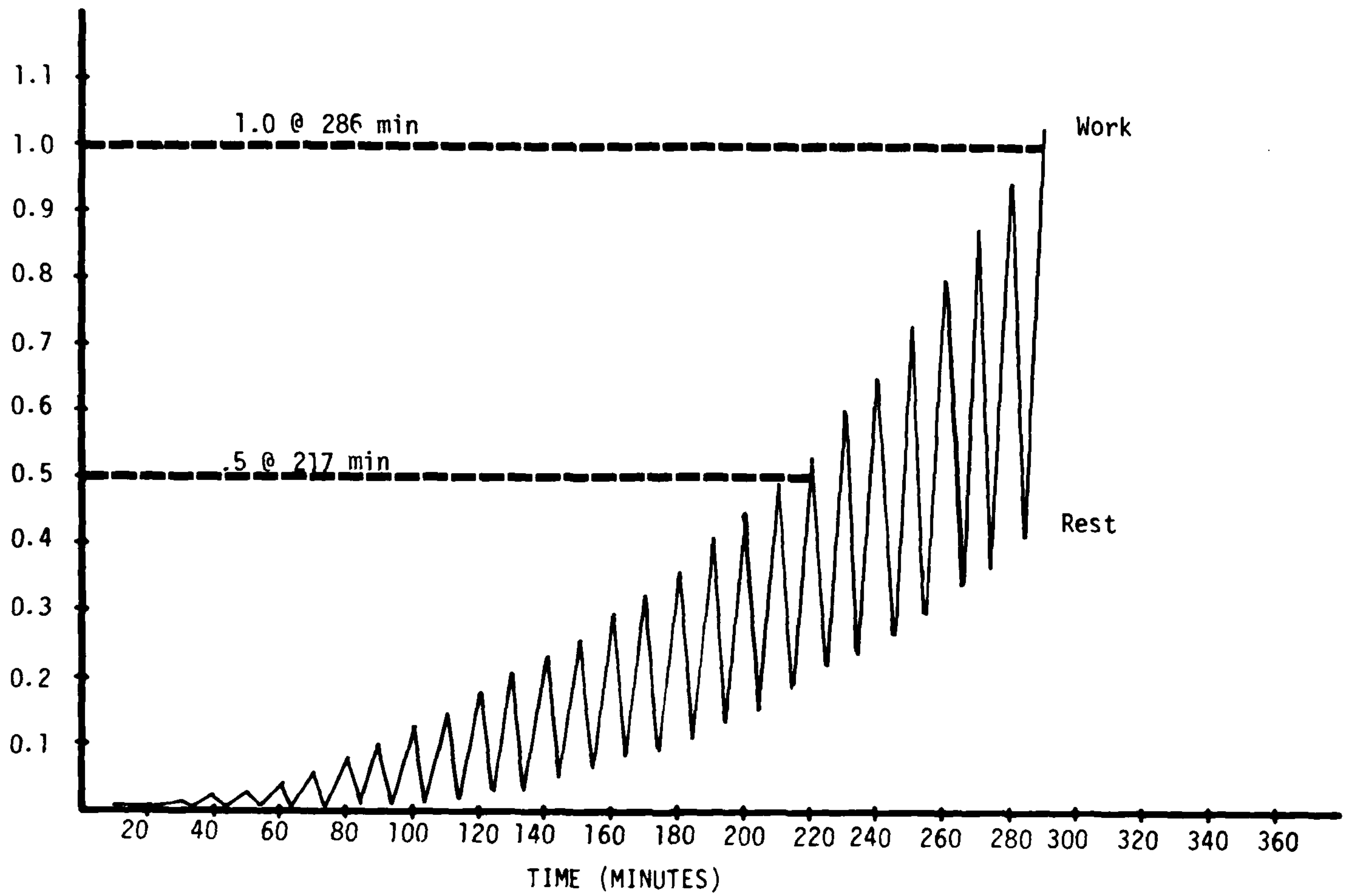

FIGURE 45 % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 13

DEPTH (FSW): 150 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 60 NET ABSORBENT WGT: 8# CONTENT %: 14.8

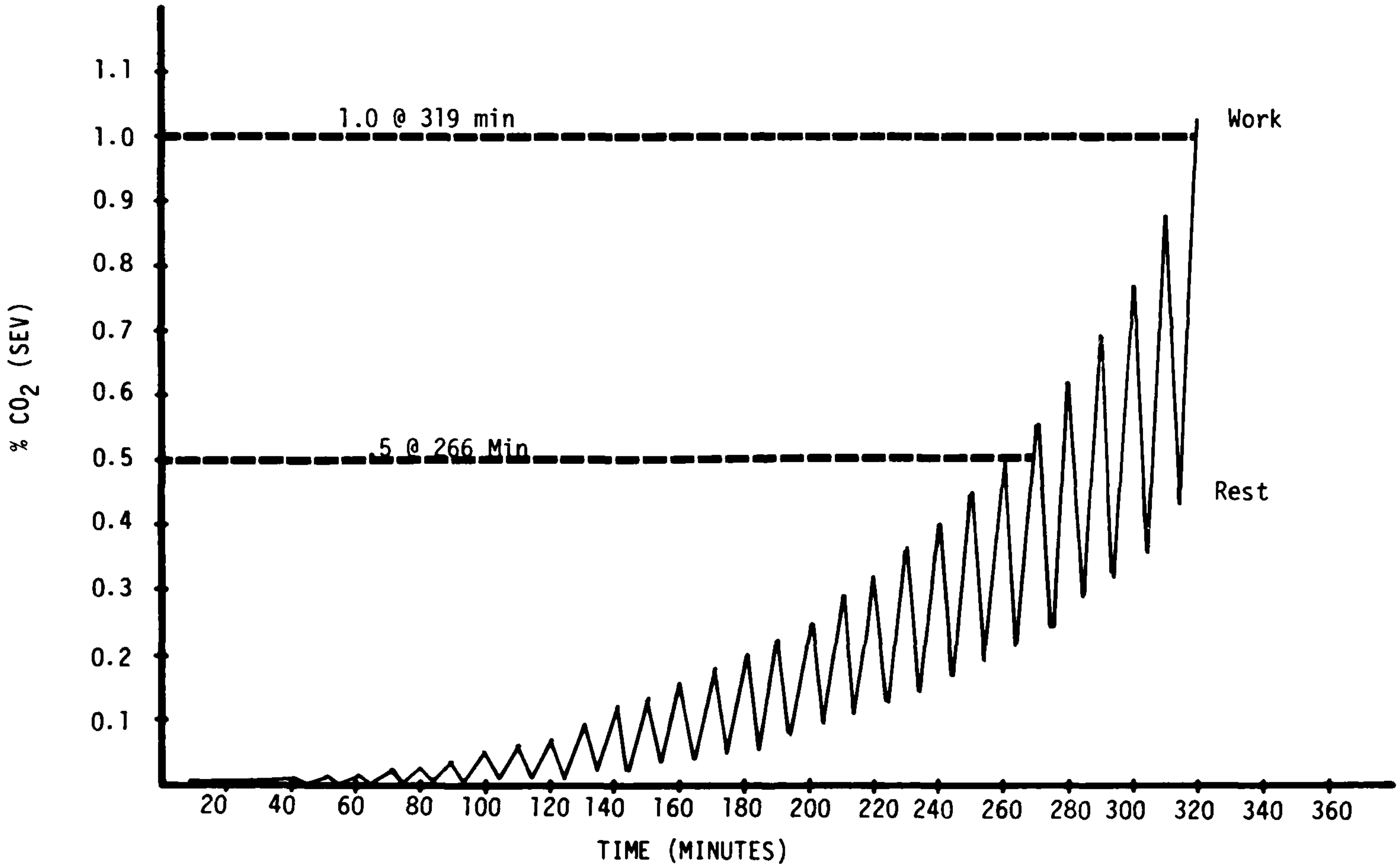

FIGURE 46 % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 14

DEPTH (FSW): 150 DILUENT: Air ABSORBENT MOISTURE

TEMP. (°F): 70 NET ABSORBENT WGT: 8# CONTENT %: 14.2

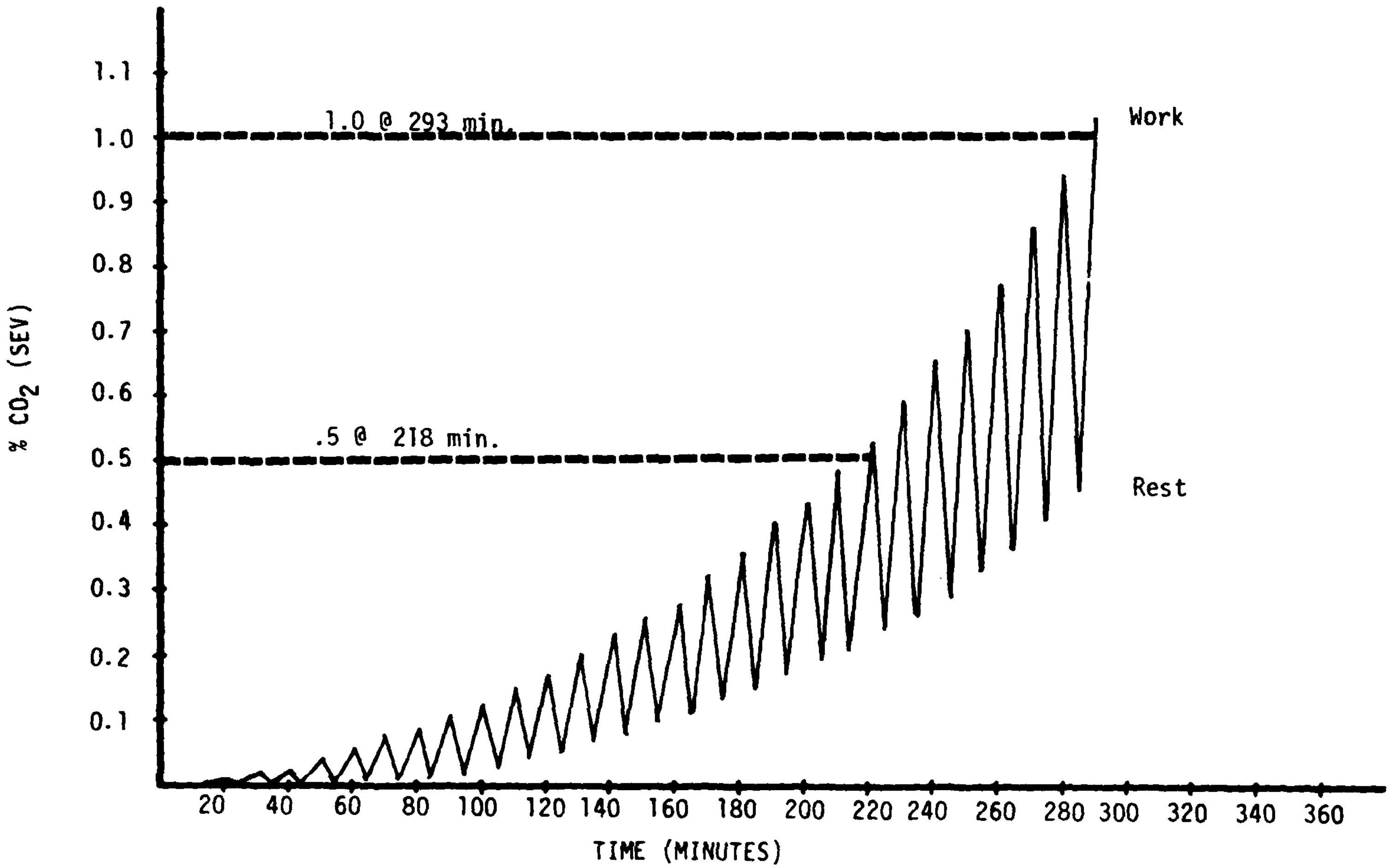

FIGURE 47 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 15

DEPTH (FSW): 30 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 40 NET ABSORBENT WGT: 8# 2 oz CONTENT %: 14.5

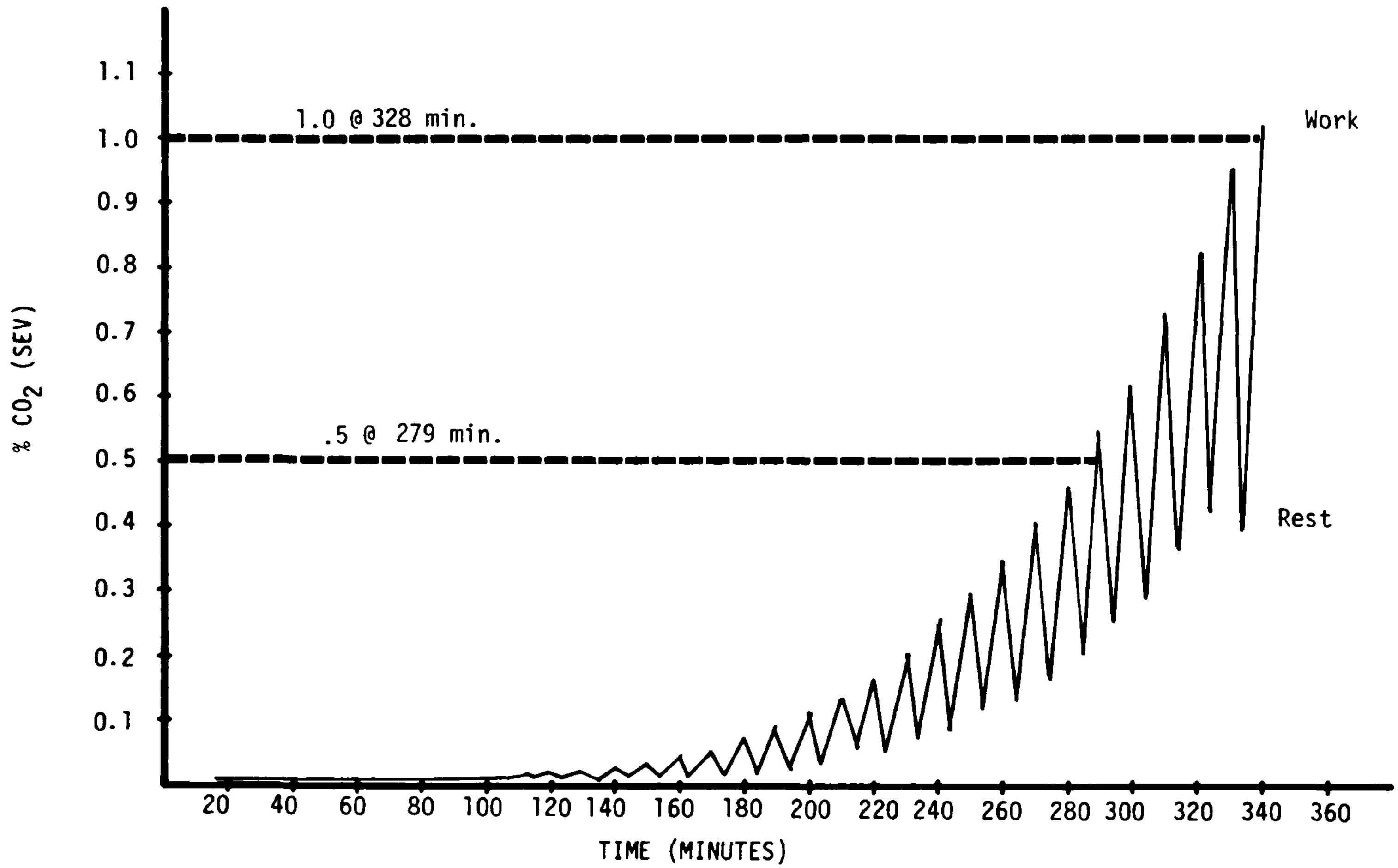

FIGURE 48 % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 16

DEPTH (FSW): 100 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (^oF): 29 NET ABSORBENT WGT: 8# CONTENT %: 14.5

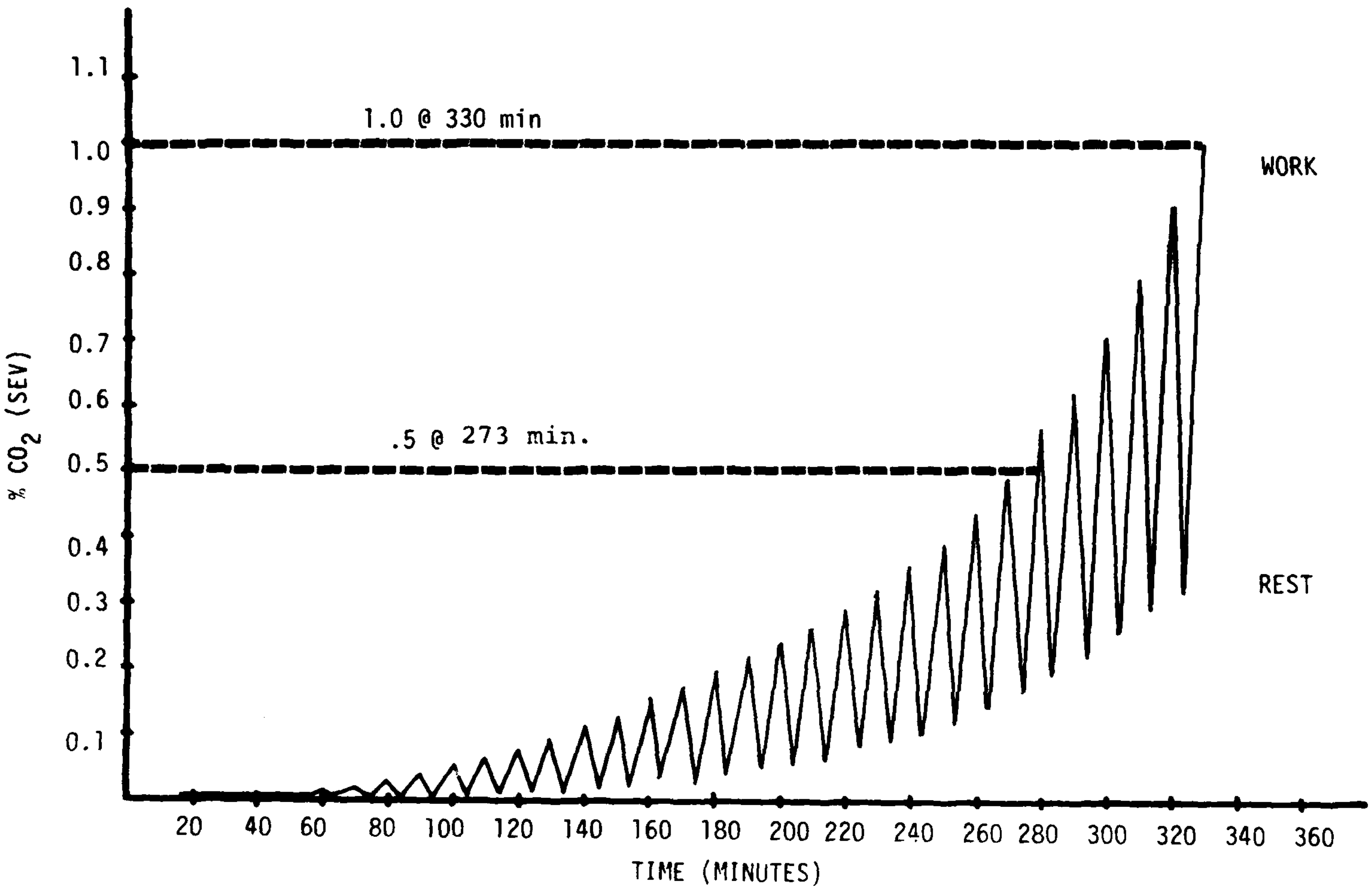

FIGURE 49 - CO_2 Vs TIME

FY 16 UNMANNED TEST / RUN NO.: 17

DEPTH (FSW): 100 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP (°F): 70° NET ABSORBENT WGT: 8# 2 oz CONTENT %: 14.4%

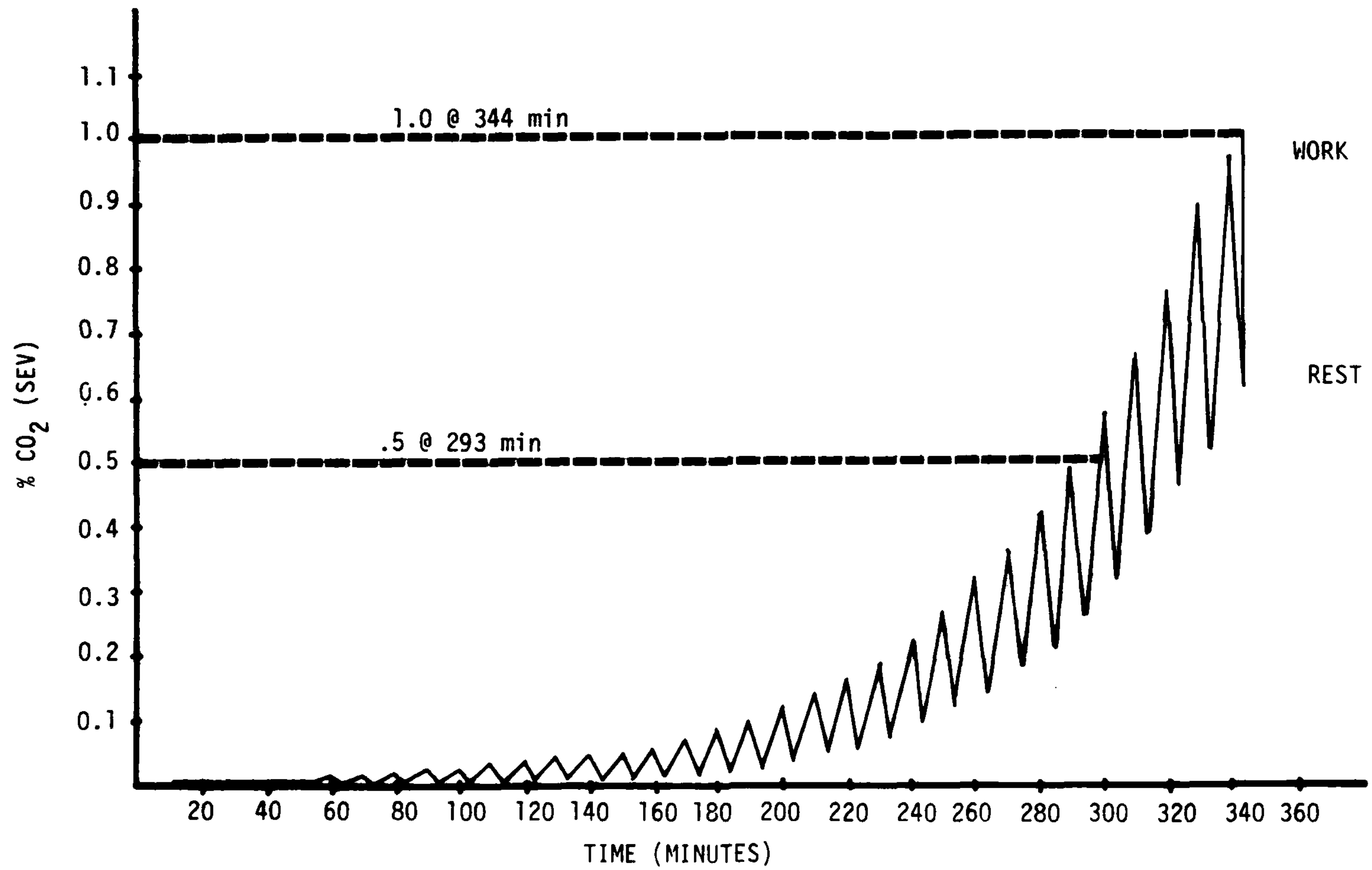

FIGURE 50 - % CO_2 Vs TIME

EX-16 UNMANNED TESTING /RUN NO.: 18

DEPTH (FSW): 150 DILUENT HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 29 NET ABSORBENT WGT; 8# CONTENT % 14.5

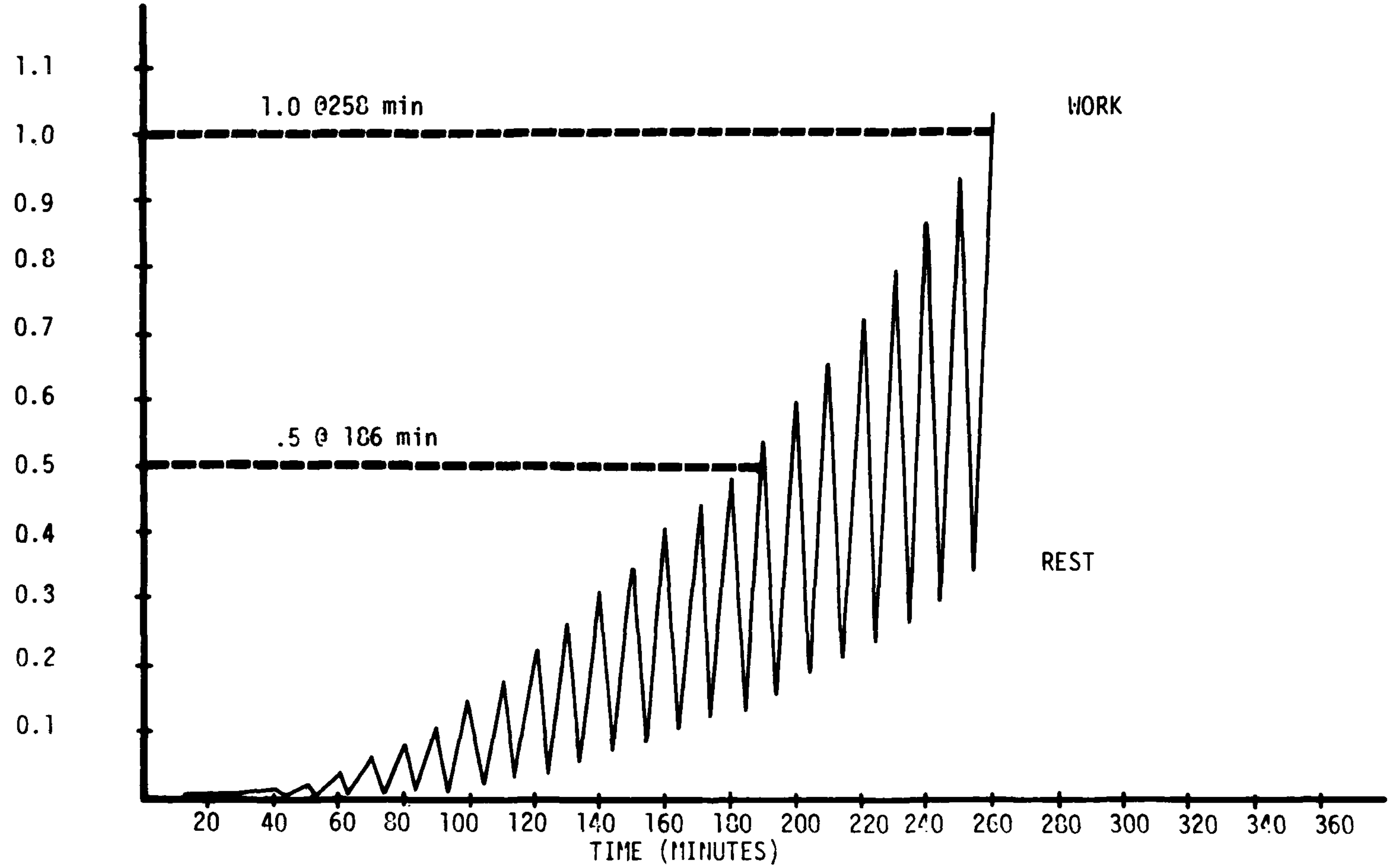

FIGURE 51- % CO_2 VS TIME

EX-16 UNMANNED TESTING /RUN NO.: 19

DEPTH (FSW): 150 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 40 NET ABSORBENT WGT: 8# 1oz. CONTENT %: 14.7

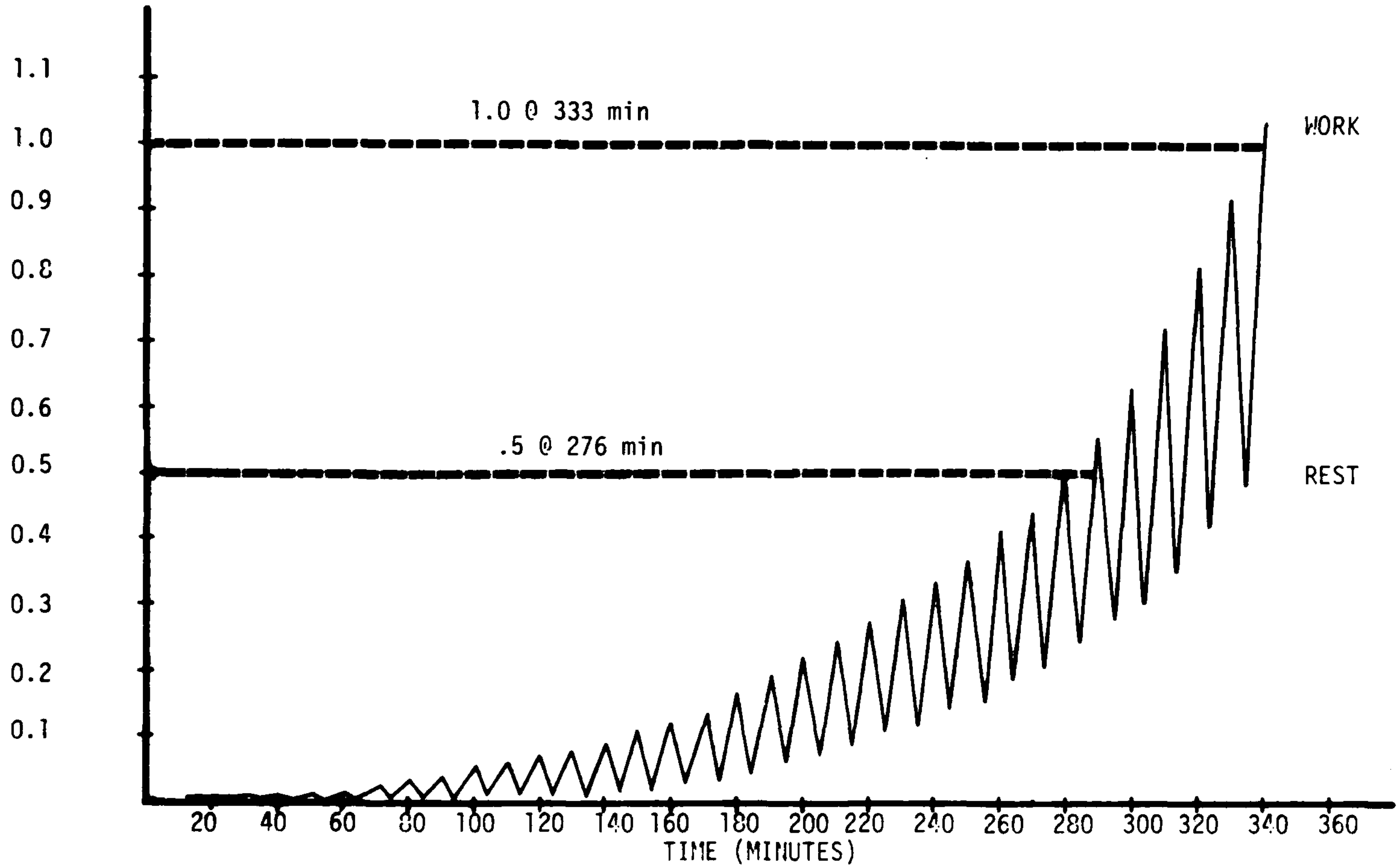

FIGURE 52 - % CO_2 VS TIME

EX-16 UNMANNED TESTING / RUN NO.: 20

DEPTH (FSW): 200 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 29 NET ABSORBENT WGT: 8# CONTENT %: 14.5

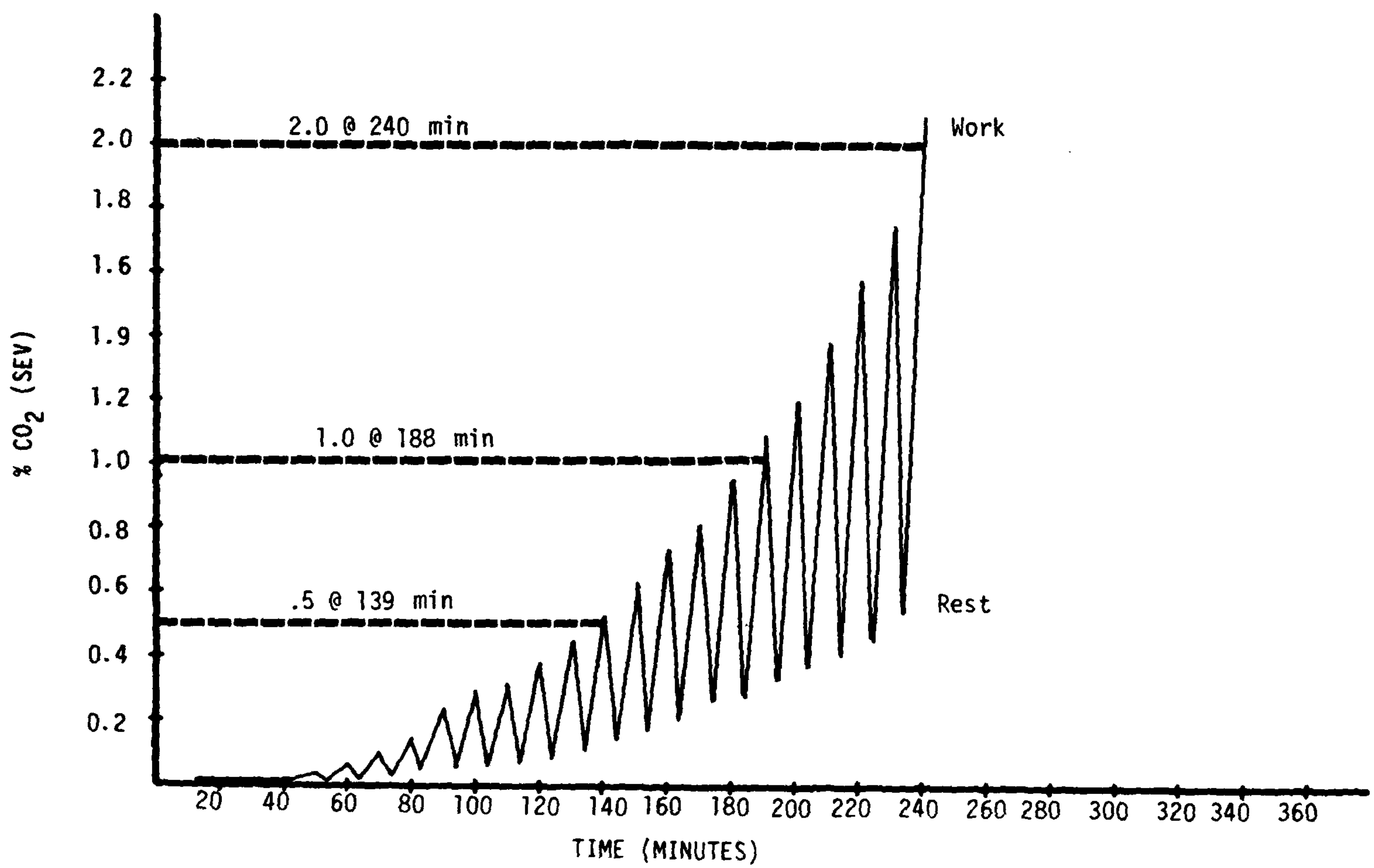

FIGURE 53 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 21

DEPTH (FSW): 200 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 40 NET ABSORBENT WGT: 8# 5 oz CONTENT %: 14.0

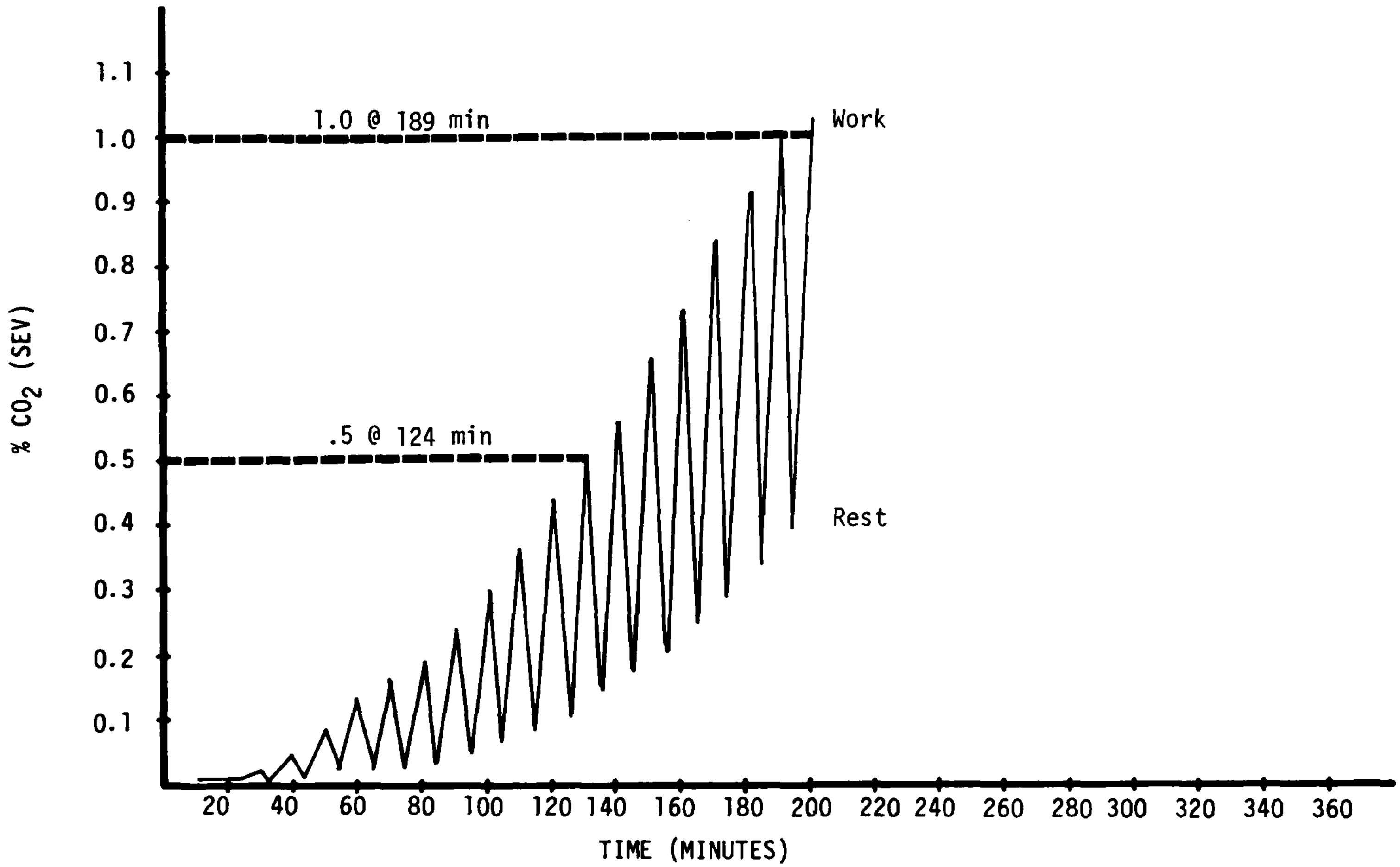

FIGURE 54- % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 22
DEPTH (FSW): 200 DILUENT: HeO_2 ABSORBENT MOISTURE
TEMP. (°F): 50 NET ABSORBENT WGT: 8# CONTENT %: 13.9

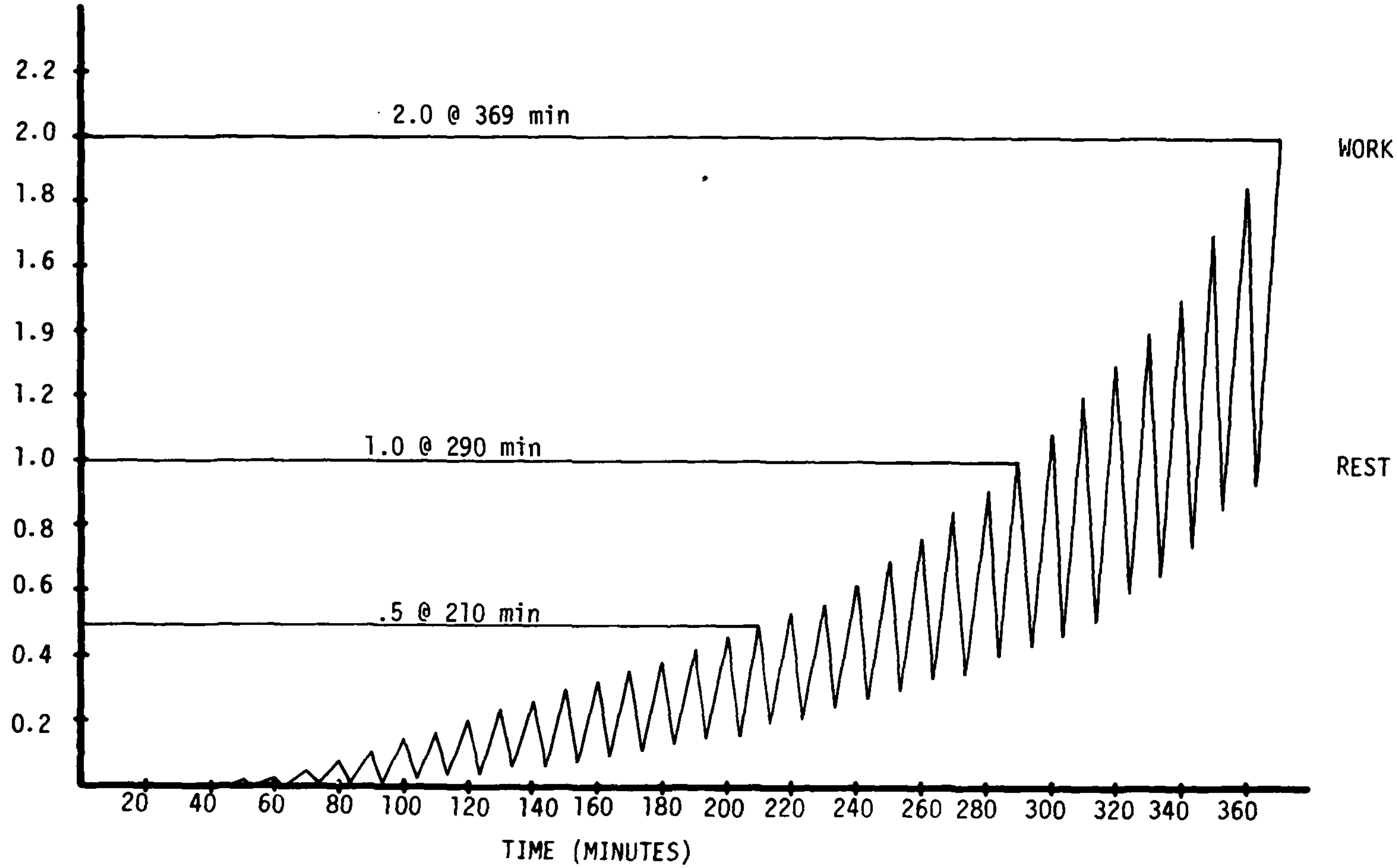

FIGURE 55 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 23

DEPTH (FSW): 200 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 60 NET ABSORBENT WGT: 8# 3/4 oz CONTENT %: 13.8

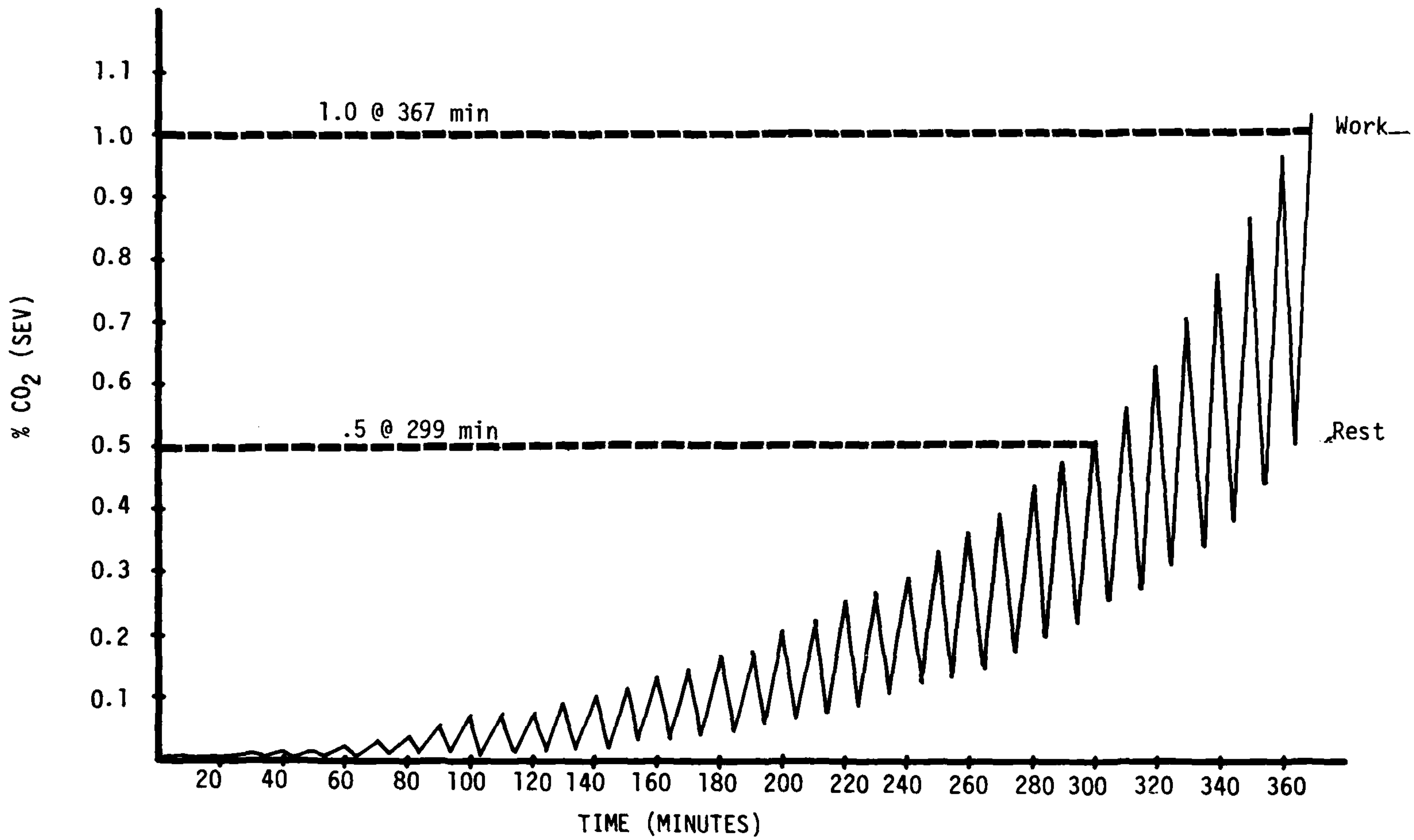

FIGURE 56- % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 24

DEPTH (FSW): 300   DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 29   NET ABSORBENT WGT: 7# 15 1/4 oz   CONTENT %: 13.5

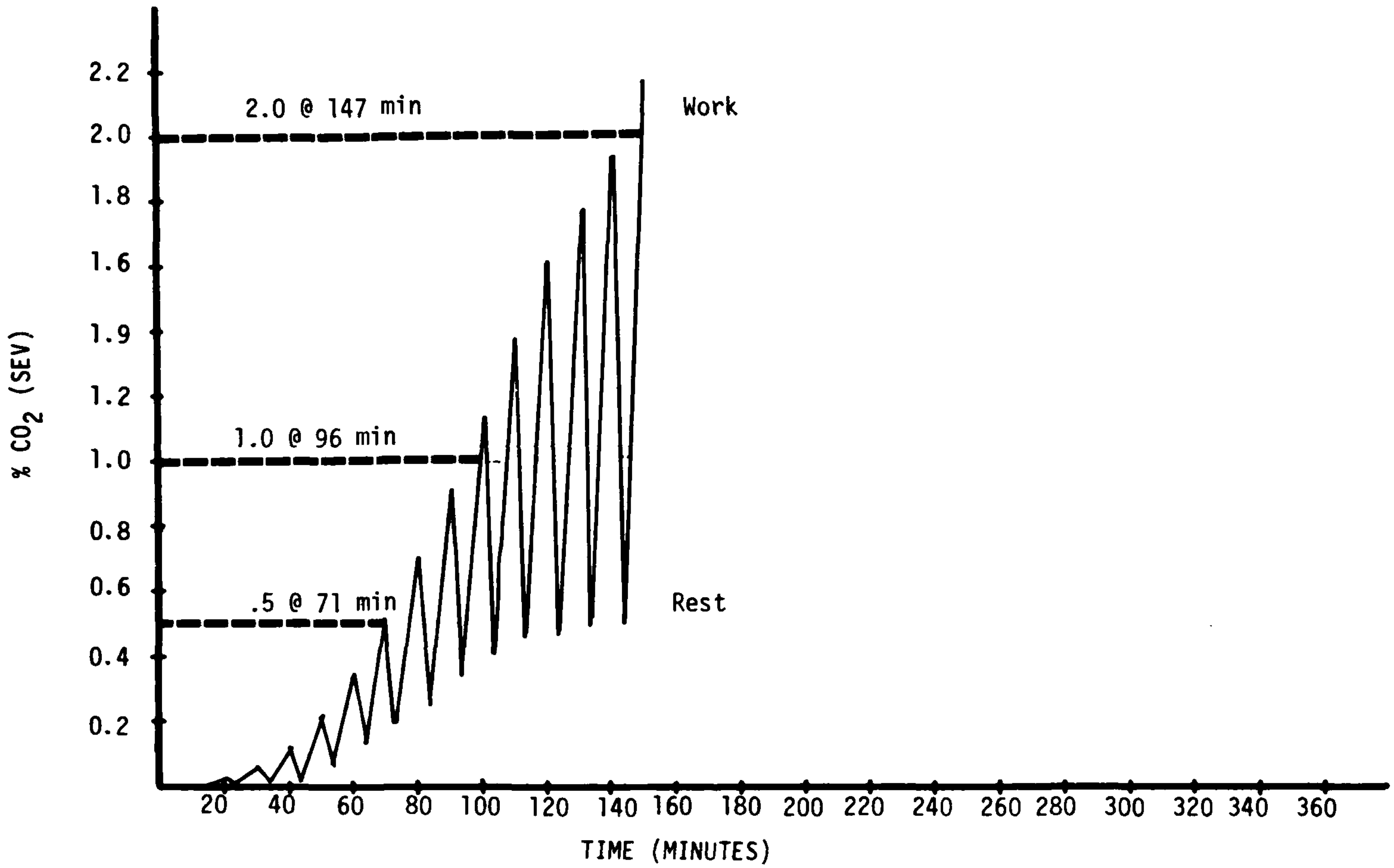

FIGURE 57 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 25

DEPTH (FSW): 300 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (^{o}F): 40 NET ABSORBENT WGT: 7" 14.5 oz CONTENT %: 14.2%

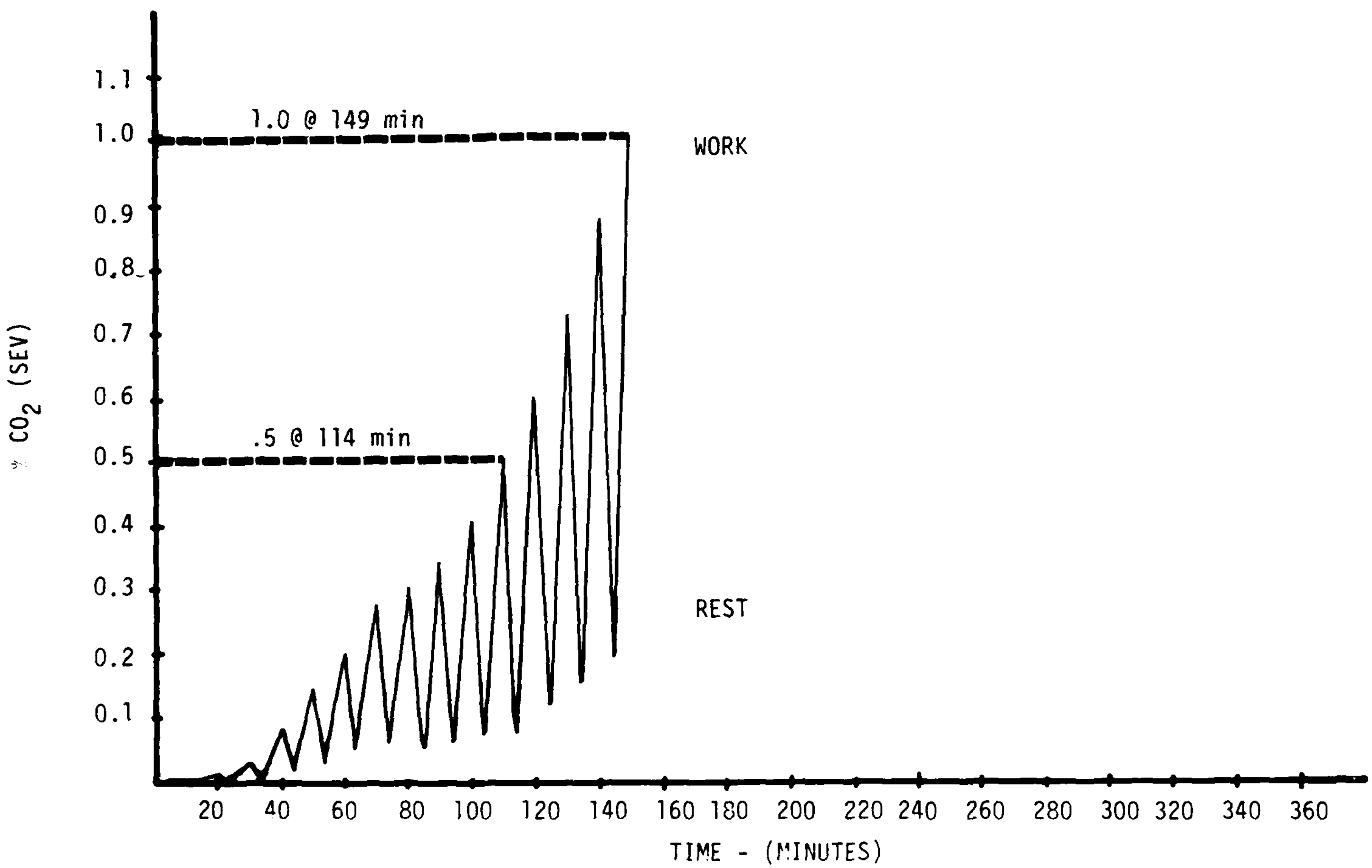

FIGURE 58 - % CO_2 Vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 26

DEPTH (FSW): 300 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 50 NET ABSORBENT WGT: 8 # 2.5 oz CONTENT %: 14.8

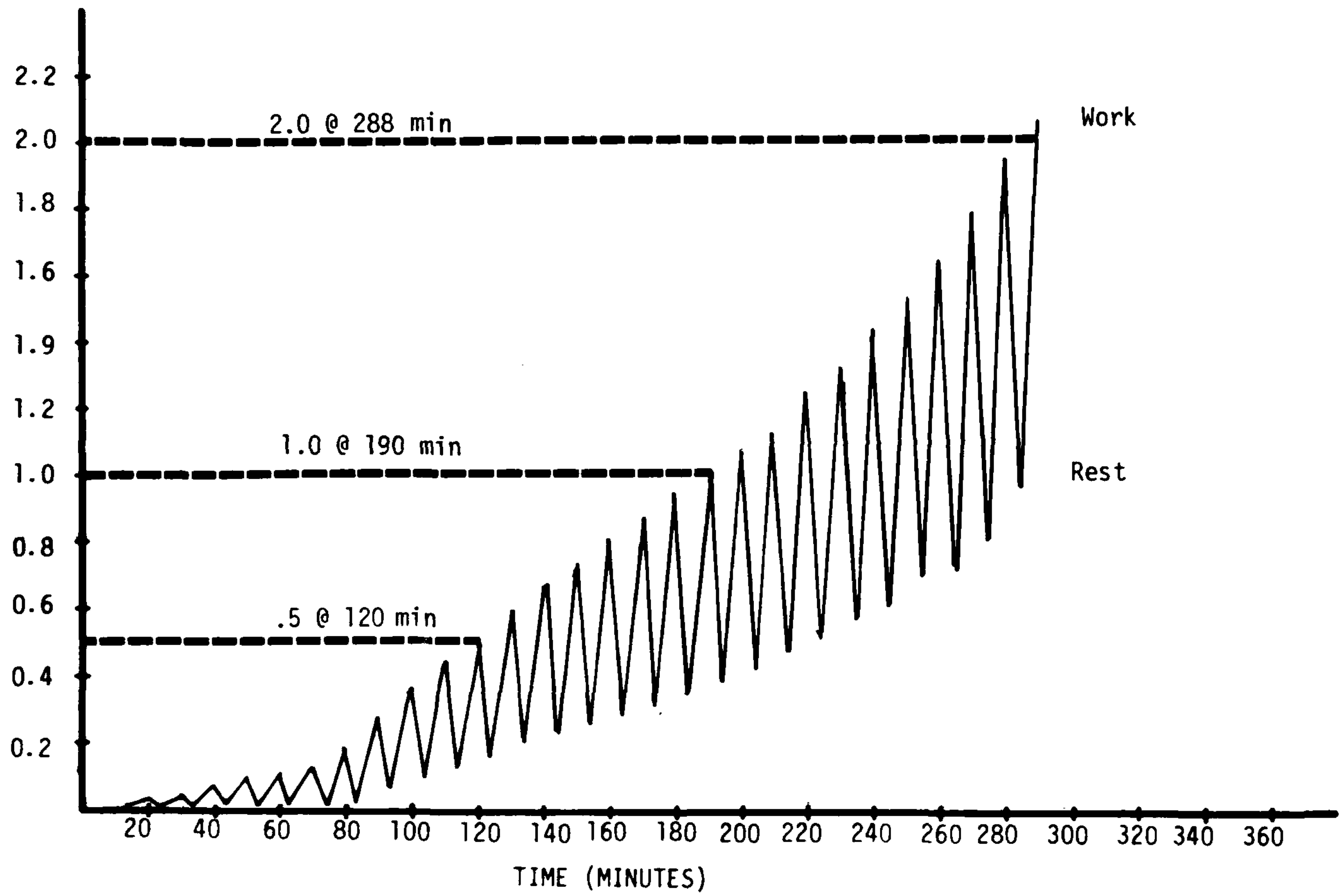

FIGURE 59 - % CO_2 vs TIME

EX-16 UNMANNED TESTING / RUN NO.: 27

DEPTH (FSW): 300 DILUENT: HeO_2 ABSORBENT MOISTURE

TEMP. (°F): 70 NET ABSORBENT WGT: 8# 2 oz CONTENT %: 14.5

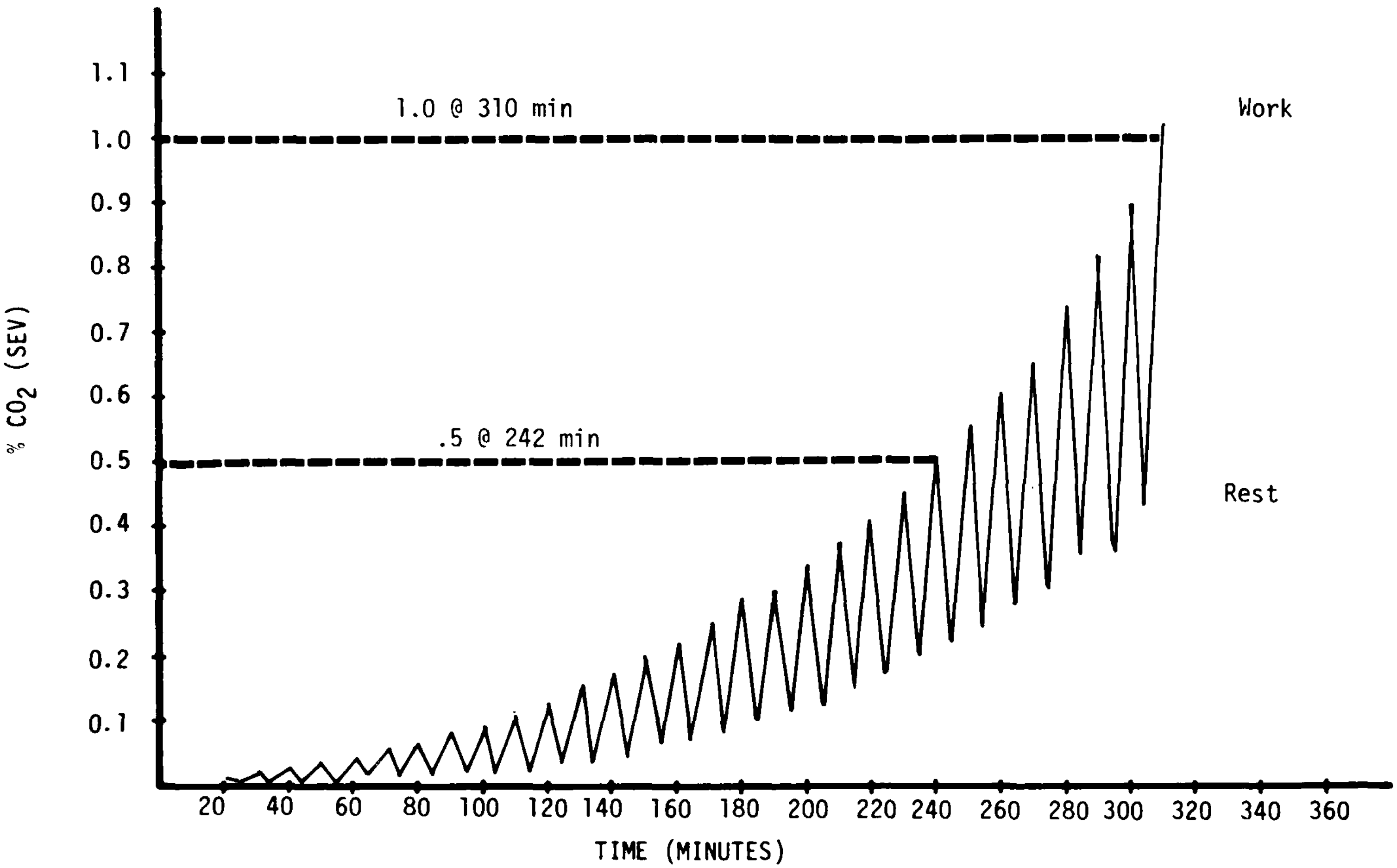

FIGURE 60- % CO_2 vs TIME

APPENDIX G

Oxygen Consumption Data
Figure 61

EX-16 UNMANNED TESTING

DILUENT: Air

DEPTH: 33 FSW

O_2 CONSUMPTION RATE: 2.0 LPM @50 RMV

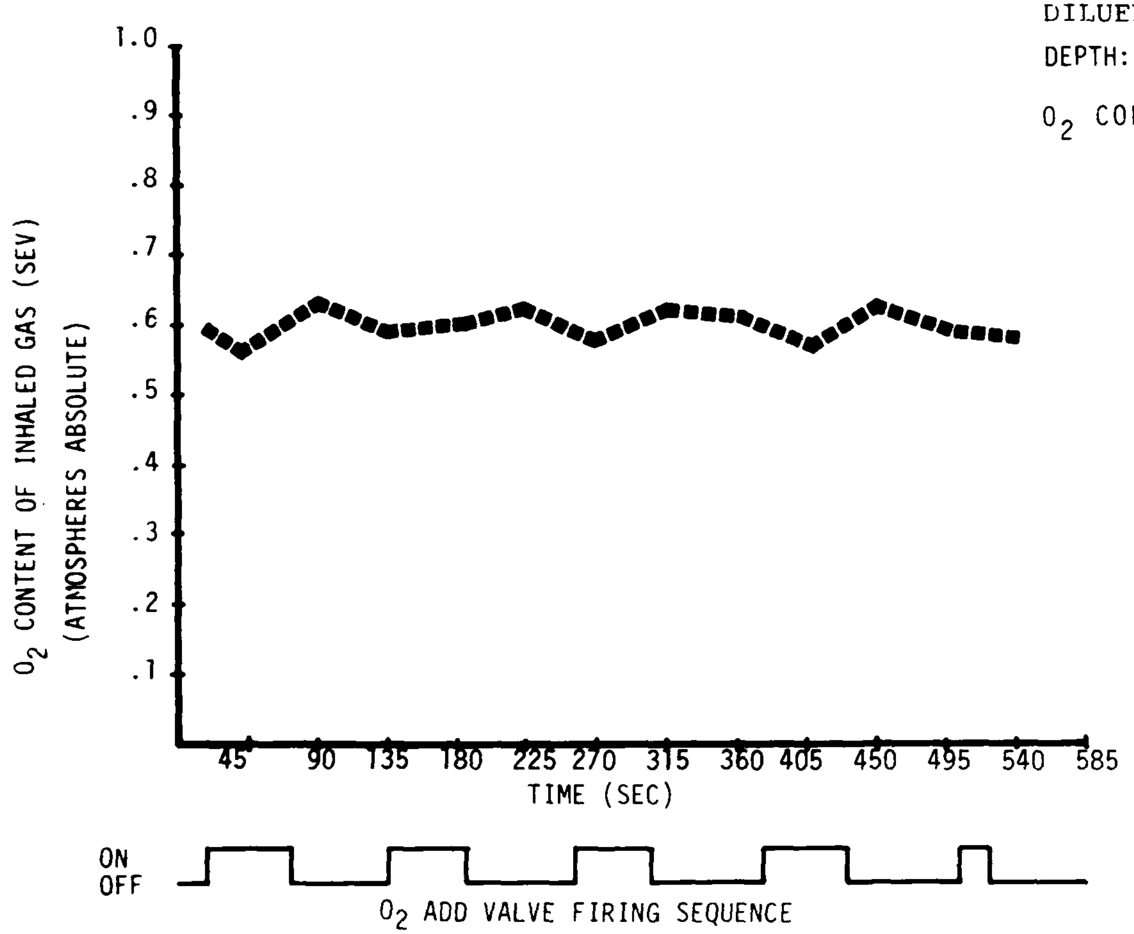

FIGURE 61 - O_2 CONSUMPTION TEST